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Monitoring and Assessment of Sediment Basins at Highway Construction Sites

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To the Graduate Council:

I am submitting herewith a thesis written by Payton MacKenzie Smith entitled "Monitoring and Assessment of Sediment Basins at Highway Construction Sites." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

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Monitoring and Assessment of Sediment Basins at Highway Construction Sites

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ABSTRACT

Sediment basins with outlet orifice skimmers are one of forty erosion prevention and sediment control (EPSC) devices that the Tennessee Department of Transportation (TDOT) utilizes to meet regulatory runoff quality permitting requirements at their highway construction sites. Regulations set in place by the US Environmental Protection Agency (US EPA) and Tennessee Department of Environment and Conservation (TDEC) require performance standards that often affect TDOT's existing design criteria for stormwater control measures (SCM). TDOT has a need to update their manual's engineering design criteria for sediment basins based on new regulations and extended data sets, including field verification.

The goal of this thesis is to begin performance analysis of current TDOT design criteria for sediment basins, basing the basin sizes on Neff and Schwartz's (2013) modeling efforts and other basin attributes on TDOT's Drainage Manual. This study monitored the influent and effluent of two separate highway sites with varying catchment slopes, soil types, and drainage areas. The monitoring devices used at each site were chosen for the locational constraints; the following were collected for six and five collection events: inlet and outlet water samples, flume sediment deposits, weather data, and volumetric flow data. The field data was analyzed to assess basin performance and characterize particle size variability.

Results showed that the Morgan County and Knox County basins performed an average of 76.8% and 97.4% mass sediment reduction between the influent and effluent, respectively. There was a large difference in contributing sediment masses, Morgan County had an average inlet mass of 1.93×10^{3} kilograms of soil, where Knox County had an average of 1.60×10^{-3} kilograms. RUSLE2 modeled sediment yield for Morgan County resulted in 19.0 t/ac compared to a field value of 22.0 t/ac; Knox County resulted in 3.8 t/ac compared to field value of 0.13 t/ac. Findings emphasize that sediment basins are not going to be the most cost efficient and appropriate BMP at every highway construction site, but when they are, it is critical that they are designed appropriately and implemented with care, taking into account alternative design changes when needed.

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1.0 INTRODUCTION

In the United States, there is an extensive history of issues with water pollution. The problem was first addressed under the Federal Water Pollution Control Act of 1948, and then amended in 1972 under the Clean Water Act. Among other things, this amendment established standards for regulating pollutant point source discharges to surface waters, called the National Pollutant Discharge Elimination System (NPDES) permit program (US EPA 2017). In Tennessee, this permit program is regulated by the Tennessee Department of Environment and Conservation (TDEC) under the Division of Water Pollution Control (TDEC 2012). One point source pollutant that TDEC helps to mitigate is sediment. According to the Environmental Protection Agency (EPA), sediment is the most common pollutant in reservoirs, lakes, rivers and streams and causes nearly 16 billion dollars in environmental damage annually. Nearly 70% of sedimentation impairment is due to anthropogenic activity and not natural erosion (MARC n.d.). Sediment is transported from various sources, such as agriculture, construction, and urban land. However, the most concentrated source of sediment erosion is active construction sites. In the 1970s, 10% of all sediment being deposited in surface waters was from construction activity, even though only 0.007% of U.S. land contained construction activity (Willett 1980). The high sediment contribution is attributed to the first soil layer maceration from heavy construction equipment, exposing a compacted soil surface below, resulting in high runoff and high sediment transportation (Fennessey and Jarrett 1994).

Under Tennessee's General NPDES Permit for Discharges of Stormwater Associated with Construction Activities, TDEC is able to regulate sediment point source pollution from highly erodible construction sites. In 2010, TDEC required a statewide 80% removal of total suspended solids (TSS) for construction discharge if the first inch of precipitation could not be retained (US EPA 2011). On January 4th, 2011 the EPA implemented more stringent numeric regulations that indicated construction sites must adhere to a strict turbidity standard of 280 Nephelometric Turbidity Units (NTUs) or less per day for stormwater discharge. This was applicable to 20-acre sites or larger by August 1st, 2011 and 10-acre sites or larger by February 2nd, 2014 (Walters 2011). The numeric rule set in place by the EPA was withdrawn January 3rd, 2012 for additional research (Schaner and Farris 2012). The current regulations by TDEC indicate that the "stormwater discharge must not cause an objectionable color contrast in the receiving stream" (TDEC 2012). The regulations also include that the "discharge not cause a condition in which visible solids, bottom deposits, or turbidity impairs the usefulness of the waters of the state for any of the uses designated for that water body by TDEC Rules, Chapter 1200-4-4" (TDEC 2012). As of 2016, the Tennessee general permit for discharges from small municipal separate storm sewer systems indicates discharge criteria of over 80% TSS removal. These regulations help to reduce sediment transport from off construction sites and standardize the way that many companies and governmental entities control erosion. It is required by Tennessee and federal laws under the NPDES permit program that when disturbing over 1-acre of land, one must create a complete stormwater pollution prevention plan (SWPPP). As regulated under TDEC jurisdiction, the Tennessee Department of Transportation (TDOT) is required to implement a SWPPP when necessary. All of TDOT's prevention plans include the standard design and implementation of best management practices (BMPs) (TDEC 2012).

TDOT and other state transportation agencies have multiple challenges when dealing with the design of highway construction site BMPs. Beginning financially, budgeting for the construction and maintenance of these highway systems includes the cost of stormwater management. Designing to minimize the cost of the stormwater system and still meet the pollutant discharge criteria is essential. Another issue with designing for highway systems is the linear nature of the sites. Only having access to the right-of-way (ROW) limits the size and orientation of designing BMPs. Purchasing additional land for the implementation of larger BMPs is not a cost-effective practice (Iyer 2007). Linear shaped corridors also affect design through hydrologic means. The typical method of designing BMPs suggests the catchment area and runoff volume be surmised from the total contributing area. In the case of highway corridors, the exposed soil surface is often a series of linear drainage networks, whose runoff lead to different locations (LIDC 2006). The method is the same regardless of the linearity of the construction site; basing the design on the total exposed surface area is not typically accurate, using this method will often result in an oversized BMP. These catchment delineation issues are even further accentuated by variable topography; this can be particularly challenging in Tennessee with its unique transition from valleys to mountains across the state. The topography influences another issue in BMP highway site design, off-site drainage. Although the water is not originating from the active construction site itself, this extra water and potentially sediment will have to be incorporated into the design, whether it is routed around the BMP or through it (Iyer 2007). The uniqueness of highway construction sites highlights the importance of determining the proper BMP and designing it to effectively suit the individual site.

An effective BMP can be categorized into two different methods: erosion prevention and sediment control. Erosion prevention successfully protects the surface of the land from eroding. This can be done by either holding the soil in place or directing runoff to a stable location. Some examples are: vegetative cover, ditch check dams, slope drains, berms, and diversion channels. Sediment control takes already detached particles and keeps them from entering streams or leaving the construction site. Sediment control can be accomplished by either slowing flow velocities or filtering sediment out. This is often a method used in addition to erosion prevention. Some examples of sediment control are: silt fences, catch basin protection, sediment traps, and sediment basins. It is also notable that a BMP can be either or both erosion prevention and sediment control (TDOT 2012). Currently the most frequently used erosion control and sediment prevention tools by TDOT are silt fences, silt fences with wire backing, rock check dams, enhanced rock check dams, and sediment tubes (Hangul 2017). These devices are not intended to replace stabilization and seeding and should be paired with other erosion control practices.

A less frequently used but useful alternative for sediment control is the sediment basin. These are typically designed and implemented at sites that have a drainage area of 10 to 50 acres; however, if the receiving waters have been classified as impaired or high-quality, a basin will be required at contributing areas as small as 5 acres. Sediment basins can either be temporary or permanent and provide storage for a volume of runoff from a 2 or 5-year, 24-hour storm. Sediment basins traditionally contain a sediment storage area, permanent pool, forebay, principal and emergency spillway, embankment, outlet protection, and dewatering system (Figure B-1). The basins are typically designed such that clean water over undisturbed soil is routed around the basin and only sediment laden water is transported into the basin; this cuts down on the volume of basin needed to treat the water. If routing the clean water around is not an option, the basin volume needs to be sized to account for the clean water passing through it.

Sediment basins are an important method for capturing the sediment coming from exposed slopes; nonetheless, there are some limitations to their use and design on construction sites (TDEC 2012). Large drainage areas are often hard to effectively route into one location, particularly in the ROW of a highway construction site. Designed using the typical exposed area method can result in large catchment area predictions; a large contributing drainage area can present a challenge by causing a basin to have an excessively tall bank height. If the embankment height is designed to exceed 20-feet, this could have the potential for sliding failure. A basin of this size would not typically fit on a TDOT site and would not be effective (TDOT 2012). In addition to the previous issues, the TDEC required length to width ratio of the basin is 4:1; this ratio is required due to the tendency of basin short-circuiting when the design size is reduced, bringing the inlet and outlet closer together (TDEC 2012). Short-circuiting is when the inlet water to the pond is directed to the outlet with minimal settling time, causing sediment laden water to flow from the basin outlet (Glenn and Bartell 2008). This issue is often remediated by building basins for larger drainage areas and utilizing a reasonable length to width ratio. A common factor in BMPs is the requirement of long-term maintenance, but this factor is especially critical for sediment basins. Over time, with enough deposited sediment, the skimmer can become clogged and the basin's performance is jeopardized (McCaleb and McLaughlin 2008). The overfilling of a basin due to inconsistent maintenance during site stabilization, especially for smaller basins, can also lead to failure (Zech, 2012). According to Hangul (2017), the seemingly high maintenance aspect of sediment basins is often a deterrent when contracting BMP designs in TDOT highway projects. Regardless of these limitations, sediment basins can be a useful tool when the true contributing drainage area is large enough to warrant the design. A large exposed area routing into a well-designed sediment basin provides flexibility to contractors who can work freely in the disturbed area (Hangul 2017).

There has been a minimal amount of sediment basin monitoring efforts on highway construction sites. The challenge with monitoring and quantifying sediment volume, particularly at a highway construction site, is understandable. McCaleb and McLaughlin (2008) analyzed a construction site sediment basin designed for a 25-year storm with a floating skimmer outlet, solid riser spillway, and porous baffles. This basin retained up to 99% of the sediment that entered the basin until the skimmer became bogged down, requiring maintenance. The effluent water at this site was still incredibly turbid, with an average of 1,070 NTUs, emphasizing the commendable decision of the EPA to withdraw its 2011 turbidity standard. In a study conducted by Fang et al. (2015), a sediment basin was constructed on an active highway construction site, equipped with baffles, a floating skimmer, and polyacrylamide (PAM) flocculant blocks. The mass reduction for the first event, where the PAM blocks were implemented correctly, was 97.9% of the sediment. The second event, where the PAM blocks were not used correctly, was 83.7%. The TSS reduction for the first and second event were 96.6% and 76.0%, respectively.

Apart from a few similar studies, more discussed in Section 2.2, there is minimal published research about sediment monitoring efforts on highway construction sites, the closest comparable data is from general construction sites and field scale regulated monitoring research. There is a clear void in research and need for more information.

In 2011, TDOT recognized the utility of sediment basins for certain highway sites, realizing the need to redo their sediment basin design, they employed expertise from the University of Tennessee. The resulting plan was to first model basin sizes that would meet future EPA and TDEC effluent standards. This was done through hydrological and sediment modeling using TR-55, HydroCAD, RUSLE2, and SEDCAD. The modeling efforts resulted in a simple sizing table for catchment areas ranging from 5 to 50 acres in regions distinguished by Knoxville, Nashville, and Memphis (Table A-1). In addition, floating skimmer sizes were included because of their requirement in current TDOT basin design (Table A-2) (Neff and Schwartz 2013). The report for phase one resulted in valuable modeled data, yet there was still information missing for field data. The lack of highway construction site monitored sediment basin data, especially based on Tennessee standards and implemented in state, lead to the next phase. The second phase of the project was to analyze field data from active TDOT highway construction site sediment basins.

The approach for phase two was to begin by analyzing field data and suggesting ways to improve the current TDOT design. This included monitoring multiple highways site basins and utilizing RUSLE2 to compare values found in the field to modeled results from the program. Exploring this comparison brought a valuable tool into the discussion, one that can be utilized to calculate required storage volumes (NCDOT). Being cognizant that there are limitations to this method, highlighting that RUSLE2 computes rill and interill erosion from slopes, not channelized flow. Regardless, the simplicity of this tool for design sediment storage in basins is the best available technology. The following research is the beginning of phase two research and an extension of the research by Neff and Schwartz (2013).

This thesis addresses the lack of sediment basin performance data at highway construction sites, and the need to update TDOT's design criteria based on better basin performance data and sediment yield models. The objectives of this research were to: 1) quantify sediment basin performance at active highway construction sites for variability in sites (soil type, catchment slope and drainage area size) and 2) estimate sediment yields from the highway construction site catchments to compare to RUSLE2 values in order to quantify sediment volume for sediment basin design. The term performance includes the total sediment captured but also the shift in particle size distribution (PSD) from approach area deposition, influent water sediment, basin sediment deposited, and effluent water sediment via the knowledge that sediment basins should settle out all larger particle sizes.

2.0 LITERATURE REVIEW

2.1 Soil Erosion

2.1.1 Erosion Transport Processes

Sediment erosion and transport caused by surface water movement is represented by the following physical processes: 1) detachment (entrainment) of soil particles from the surface, 2) down-current movement of the particles along the surface, and 3) deposition of loose particles (sedimentation). The force needed for detachment is higher than the force needed to keep the particles suspended. At the particle level, the following three variables prevent sediment detachment: gravity, frictional resistance between particles, and cohesion of particles in the soil. Sediment is forced into suspension by the lateral dragging force across the soil surface and the vertical force, via the Bernoulli and Archimedean buoyancy effects (Hillel 1998). Once these physical forces take hold, the water causes various types of erosion from the soil surface: sheet/interrill, rill, and gully erosion. Sheet is the uniform removal of layers of soil. The term interrill erosion is often used in place of sheet erosion, this term refers to a form of erosion primarily caused by raindrop impact. The raindrop impact detaches soil particles, splashing them into the air and into overland flow. This increases the flow turbulence and escalates soil erosion (NSERL n.d.). The rate of interrill erosion is affected by soil characteristics, slope, and rain intensity. Rill erosion is the scouring of soil by channelized water that forms eroded divots in the soil. The rate of rill erosion is due to the soil erodibility and the critical shear (Hillel 1998). Gully erosion is similar to rill erosion but involves deeper and wider erosion and cannot be corrected by conventional tillage (NRCS 2015).

The likelihood of erosion occurring is influenced by climate, soil properties, topography, soil surface conditions, and human activities (Renard et al. 1997). Climate and soil properties include the erosivity of rainfall and the erodibility of the soil. The erosivity of rainfall is a function of the intensity, duration, and energy of the rain. Intensity is the amount of rain that falls per unit of time. Intensity is highly variable between storms, location, and seasons. Duration is how long the precipitation event lasts. Energy of the rain is the amount of kinetic energy a raindrop has on a unit of area. Erodibility of the soil, or the susceptibility for the soil to erode, can have many different contributing factors; this is typically influenced by the soil structure and texture (Hillel 1998).

2.1.2 Repercussions of Soil Erosion

Water transported sediment impacts the biological, physical, and hydrologic characteristics of streams and other surface waters. Some of these include excess nutrient deposition (biological impact), water turbidity (biological and physical), sediment deposition (biological, physical and hydrologic) (NRCS 2000). Sedimentation and turbidity can significantly affect populations of aquatic biota. Producers, invertebrates, and fish are affected by sediment transport and deposition in many different ways, as illustrated in Figure 2-1. At the basic level, sediment pollution affects the local food chain by impacting primary trophic level production rates (Henley et al. 2000). This direct detriment to the environment can be attributed to a decrease in light penetration due to increased turbidity (Wood and Armitage 1997). The resulting issue impacts food availability along the food chain and increases mortality while decreasing rates of growth and reproduction. In fact, increased turbidity has been found to be the strongest cause of decreased biomass and density of invertebrates (Henley et al. 2000). Issues due to fine sediment can occasionally become extreme enough to reduced habitat for benthic organisms, kill aquatic flora, cause channel morphology changes, smother riverbeds, increase drift in invertebrates, and clog available habitat in rock outcrops. The effects of sedimentation and turbidity can have repercussions that take months or years for both morphology and ecology in the streams to recover and may require human intervention (Wood and Armitage 1997).

Research by Ehrhart et al. (2002) specifically looked at the effects of construction site sedimentation basins on stream ecosystems. Samples were taken from three construction sites for water at two locations upstream and downstream of the system and from the basin pipe as it discharged. Their results indicated that there was not a significant decrease in number of macroinvertebrates, but there was a significant decrease in taxa observed directly below the basin. These results had a limited range, as the basin did not affect species richness 100 meters downstream (Ehrhart et al. 2002). As indicated, sedimentation has a definite impact on habitat, warranting a high emphasis on effectively preventing excessive sedimentation and turbidity from reaching ecological systems.

2.1.3 RUSLE2 Modeling

According to the United States Department of Agriculture, Agricultural Research Service (ARS), RUSLE2 uses conservation of mass to estimate long-term sediment loss on slopes due to rill and interrill erosion caused by rainfall and its overland flow. This is representative of

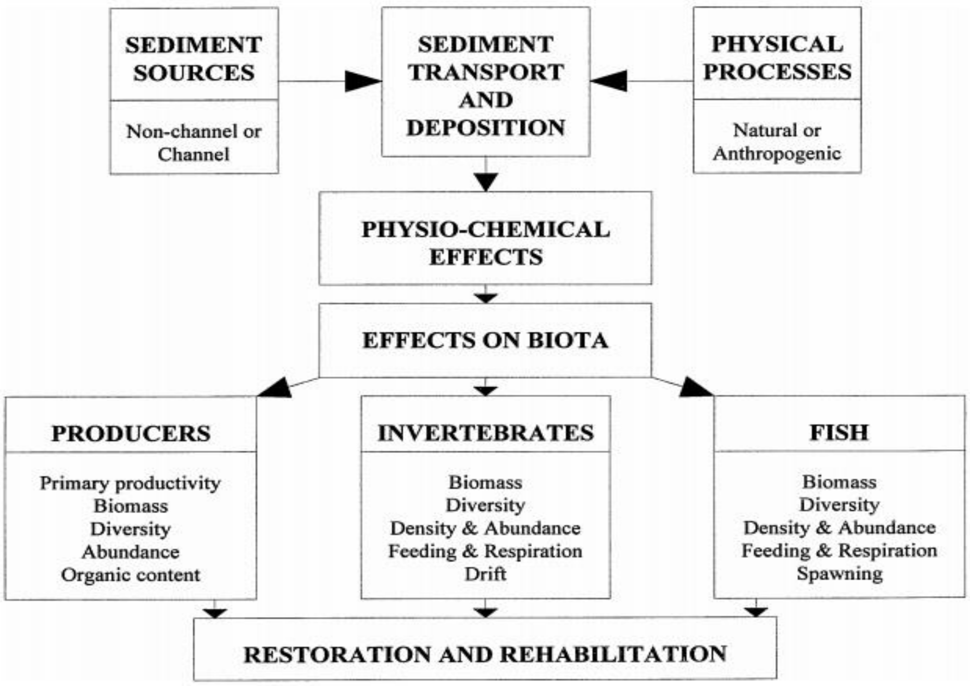

Figure 2-1. An overview of how fine sediment impacts the lotic ecosystem (Wood and Armitage 1997).

hillslope erosion but does not include channelized flow. The calculation concept is represented in Figure 2-2, showing visually how RUSLE2 computes.

To show net detachment RUSLE2 uses a variation of USLE:

$$A = RKLSCP$$

The variable A is average annual soil loss, imperially in tons per acre. The variable R is the rainfall erosivity factor, imperially in hundreds of feet by tons of force by inches, over acre hours. The variable K is the soil erodibility factor, imperially in tons of force by acre hours over hundreds of acre-feet by tons of force by inches. The variable LS is the topographic factor, utilizing L for length and S for slope to find LS, and is unitless. The variable C is surface-cover factor and is unitless. The variable P is management factor (Hillel 1998).

To represent sediment deposition, the following equation is used:

$$D = \left(\frac{V_f}{q}\right)(T_c - g)$$

The variable D is deposition rate in mass/unit area, V_f is the fall velocity of the sediment, q is the runoff rate, T_c is the transport capacity of the runoff, and g is the sediment load in mass/unit width. This variable helps to understand how sediment is deposited based on soil type, for example, larger particles (sand and gravels) will deposit before smaller fine particles (clay, silt, small aggregates) deposit. The two contributing equations were integrated together to result in the program RUSLE2 (ARS 2016).

Over time the estimation of soil loss has become more accurate with more field validated data. The resulting integrated Version 2 is more accurate than using USLE or RUSLE and can account for a difference of 20% in erosion estimates (ARS 2016). A major change from USLE and RUSLE to RUSLE2 is the use of subfactors for the C-factor. These are used to compute temporal management factors, which helps to explain how external and internal forces combine together to affect soil erosion resistance. This value includes: percent canopy cover and fall height, surface roughness, ground cover by multiple materials, plant community type, plant production, and time since the ground has been mechanically disturbed (Foster et al. 2003). The multitude of contributing subfactors makes the C-factor variable depending on what occurs over time, making the variability of construction site work particularly problematic for estimating.

There are a multitude of useful scenarios in which RUSLE2 should be utilized and some that that it should not be. According to the Tennessee Erosion and Sediment Control Handbook,

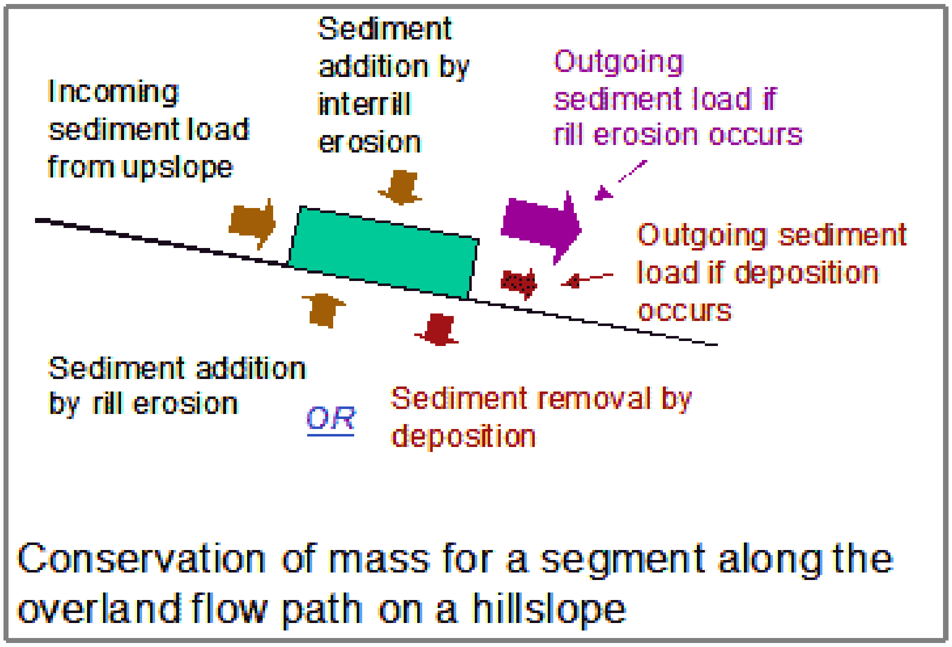

Figure 2-2. Diagram of how RUSLE2 uses conservation of mass to estimate rill and interrill erosion (ARS 2016).

ways in which this model can be used for construction planning are as follows: calculating baseline soil loss to compare scenarios, comparing soil erosion at various stages of a project, comparing practices, calculating sediment yields for phased and timed projects, diverting runoff from high-erosion areas, reduce overland flow length and reduce steepness, show stabilization results, selecting cover, selecting grade, and utilizing sediment trapping devices. There are clear limitations to the use of RUSLE2 in regulation. TDEC details the following sceneries that RUSLE2 should not be utilized for: concentrated flow, undisturbed forestland, piping caused erosion, snowmelt erosion, erosion as a result of mechanical process, organic soils, slopes longer than 1,000 feet, slopes greater than 100%, modeling a sediment basin beyond small and simple designs, and sediment basin and diversion engineering designs (TDEC 2012). Although RUSLE2 does not model sediment basins themselves, it can still be utilized to estimate values of soil loss as a rough design planning tool for sediment erosion to the basin, understanding that this does not take into account any deposition on the slope or erosion due to flow channelization (NCDOT 2015).

2.2 Basin Research

As briefly mentioned in Section 1.0, limited research has been done that conveys sediment basin performance during construction with catchment area variability in soil classification, drainage area, and slope. Performance results are particularly important at roadside construction sites where the likelihood of substantial sediment laden runoff is high. As various research is reviewed in the upcoming section, it is important to note that sediment basins are designed for during construction activity, where the term detention basin indicates long-term post-construction monitoring and do not have similar sediment input volumes. It is also critical to be cognizant of the fact that not all studies analyzed represent synonymous monitoring effort implemented in this thesis, and the intention was to accentuate the need for representative during construction data and a lack of comparable monitoring conclusions.

2.2.1 Detention Basins

In 1999 the EPA released its Preliminary Data Summary of Urban Storm Water Best Management Practices. As indicated in the report title, the data monitored is from urban storm water, typically post-construction modified basins. This included both retention/wetland and detention basins being used as stormwater management tools. Detention basins are defined as basins that provide temporary storage that release the stormwater steadily after an event.

Retention basins are defined as basins that either provided storage without releasing the water, or retained the water until the next event, in which the next storm will completely displace the existing water (EPA 1999). According to this publication, detention basins were limited to removing suspended solids and their associated contaminates. This efficiency was increased by using a forebay or pre-settling chamber and implemented periodic cleaning to avoid washout and re-suspension of sediment in following storm events. Detention basins were not designed to heavily treat runoff for contaminates, other than sediment. The EPA 1993 *Handbook Urban Runoff Pollution Prevention and Control Planning* indicated an estimated a dry detention basin TSS removal of 30% to 65%. The handbook indicated that there was a lack of monitoring and performance data of BMPs, especially detention basins (EPA 1999).

In addition, an analysis of the data in the International Stormwater Best Management Practices Database analyzed almost exclusively post-construction detention basins, rather than sediment basins. These basins were permanent fixtures at residential or commercial locations, rather than temporary basins at construction sites laden with heavy sediment concentrations. In the Final Report of the International Stormwater BMP Database 2016 Summary Statistics, the performance for TSS removal was quantified for extended detention basins. The detention basins most commonly mentioned in the BMP database had some grass or shrubs in the basin, only a few had no vegetation, concrete, combination clay/grass, or unknown conditions. In summary, all BMPs evaluated had a discharge of less than 30 mg/L median TSS effluent concentrations. TSS concentrations were lowest in bioretention, media filters, retention basins (sediment basins), and wetland basins (WERF 2017). Table 2-2 details the entirety of the BMP TSS results in various statistical terms, including inlet and outlet concentrations, where Table 2-1 acts as a legend for Table 2-2, interpreting the symbolization for the hypothesis results. Figure 2-3 displays the results as a box plot, showing the detention basin performance next to other BMPs tested.

One detention basin analyzed in the BMP Database was built in Hampton, Maryland, referenced as the Oakhampton Dry Basin. This basin was retrofitted after being built in 1984. The drainage area was 16.8 acres of high density residential and was designed to provide 29 hours of detention for a 1-year storm event. Flow measurements were taken using a Palmer Bowles flume at the inlet and a 1.5-foot H-flume at the outlet. The dry pond resulted in high to moderate values of suspended solid removal at a medium removal of 89%, where the median

Table 2-1. BMP Database legend for interpreting the hypothesis test results in the TSS performance data (WERF 2017).

Inflow-Outflow Concentration Differences	Interpretation
◆◇◇	95% confidence intervals around influent/effluent medians do not overlap.
◇◆◇	P-value of the Mann-Whitney test is less than 0.05.
◇◇◆	P-value of the Wilcoxon test is less than 0.05.

Table 2-2. BMP Database TSS (mg/L) influent and effluent summary statistics (WERF 2017).

BMP Category	BMPs		EMCs		25th		Median			75th	
	In	Out	In	Out	In	Out	In	Out	Difference	In	Out
Bioretention	25	25	520	463	18.0	4.0	40.6 (36.0, 46.0)	10.0 (8.0, 10.0)	◆◆◆	99.2	18.5
Composite	10	10	202	174	42.4	8.0	85.7 (75.0, 101.3)	18.0 (12.8, 19.2)	◆◆◆	178.8	36.5
Detention Basin	32	33	411	436	24.1	10.5	68.0 (57.4, 76.2)	24.3 (21.8, 27.0)	◆◆◆	129.0	49.6
Grass Strip	19	19	361	282	20.0	10.0	44.0 (39.0, 48.0)	19.0 (15.5, 21.0)	◆◆◆	90.0	35.0
Grass Swale	24	24	442	418	9.2	11.0	28.6 (23.0, 35.0)	24.0 (19.0, 26.0)	◇◇◆	67.5	46.7
LID	3	3	131	62	25.5	13.0	51.0 (32.0, 54.0)	29.5 (15.0, 49.3)	◇◇◇	87.5	82.0
Media Filter	25	25	400	377	22.0	3.9	56.4 (46.0, 61.9)	9.0 (6.4, 10.0)	◆◆◆	120.0	22.8
Porous Pavement	9	9	404	248	36.8	15.0	93.7 (75.0, 126.0)	26.0 (20.6, 27.0)	◆◆◆	243.0	53.2
Retention Pond	56	56	923	933	15.0	4.3	47.2 (40.0, 54.0)	11.7 (10.0, 12.3)	◆◆◆	139.8	28.0
Wetland Basin	22	22	492	486	13.1	4.7	31.0 (26.4, 35.5)	14.1 (11.6, 15.2)	◆◆◆	75.9	31.0
Wetland Basin/ Retention Pond	78	78	1415	1419	14.0	4.5	38.9 (35.6, 43.6)	12.0 (11.1, 13.0)	◆◆◆	110.3	29.6
Wetland Channel	12	12	199	178	13.0	8.0	22.0 (18.0, 24.0)	17.0 (13.0, 19.0)	◇◆◆	98.4	40.5

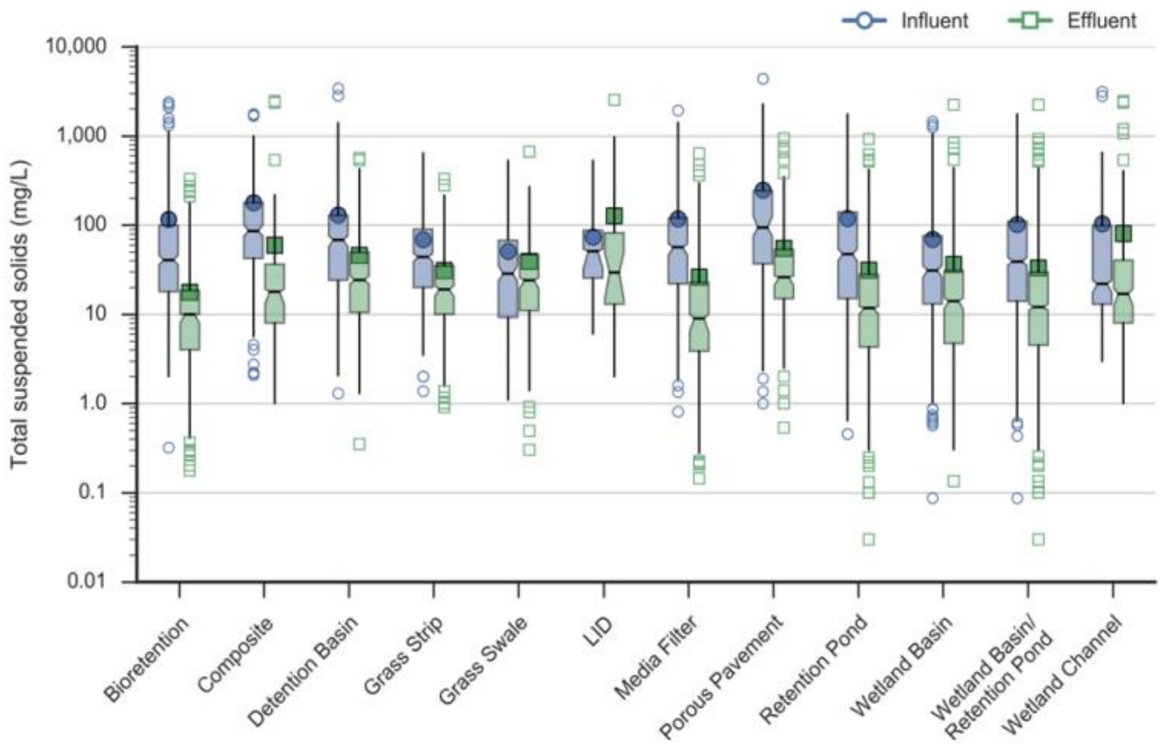

Figure 2-3. Best Management Practices (BMP) Database summary statistics box plot of influent and effluent TSS concentrations (WERF 2017).

influent concentration was 92 mg/L and the median effluent concentration was 10 mg/L. It was unclear what the inside of the basin was lined with, whether it was vegetated or left bare. It was also unclear what soil type was present at the location and what the rough slope was leading into the basin. This location, being residential, did not represent the construction site conditions that TDOT so frequently encounters (WERF 2018).

A basin was also analyzed for TSS in Charlottesville, Virginia. This was labeled under the headings Massie Detention Pond A, B, and C. Originally the pond was only designed to reduce peak flow from runoff at pre-development flow rates of 2-year and 10-year storm events. Massie Detention Pond A was the pre-retrofit sampling results, Massie Detention Pond B was the post retrofit sampling results, and Massie Detention Pond C was the sampling results from the second year of study (1993) after the flow metering results were altered. The Massie Detention Pond received runoff from a riprap-lined channel that drained from a 24-inch concrete sewer drain that received water from 4.2 acres and a concrete trapezoidal ditch that received from 1.5 acres. The alteration to this was done by reducing the orifice diameter on the outfall pipe. The original sampling of the pond had flow readings separately at the two receiving flows into the basin. For monitoring set-up C the flow was taken at a single point and altered because of suspected water back-up into the V-notch weir, this took into account submerged conditions. It is also important to note that the sampling method for testing TSS was downstream of the merging of the trapezoidal ditch and the 24-inch concrete pipe. The outflow measurement was through grab samples for individual storms. The results of TSS for Massie Detention Pond A, pre-retrofit, resulted in a median TSS reduction of 28.1 mg/L to 12 mg/L, or a 57% decrease in sediment from the inlet to the outlet. The results of TSS for Massie Detention Pond B, post-retrofit, resulted in a median TSS reduction from 16.7 mg/L to 11.6 mg/L, or a 30% decrease in sediment from the inlet to the outlet. The results of TSS for Massie Detention Pond C, post-retrofit and revamping of flow calculations, show a median reduction from 27 mg/L to 14.3 mg/L, or a 47% decrease in sediment from the inlet to the outlet. In both Massie Detention Pond B and C the reduction was not as high as the Oakhampton Dry Basin, yet the influent concentration value was drastically lower in all samplings of the Massie Detention Pond. As before, it is unclear what the slope profile and soil were characterized as at this site. It is also unclear what the cover conditions were lining the basin (WERF 2018).

Dr. Robert Pitt at the University of Alabama has multiple research documents indicating the effectiveness of various BMPs. His research details the use of detention basins on both residential and construction sites. Pitt has indicated that detention basins (dry ponds) have a lack of documented water quality benefit (Pitt 2003). In the 2003 publication "The Design, Use, and Evaluation of Wet Detention Ponds for Stormwater Quality Management" he detailed a study by Metropolitan Washington Council of Governments, Washington, D.C., in Prince George's County, Maryland of eleven different stormwater control practices. This study looked at effectiveness in both performance and longevity. Among other controls, infiltration basins and extended detention dry ponds were found to underperform. Where wet ponds and artificial marshes tended to function well for extended periods of time with minimal maintenance. He also noted that the failure of these detention ponds (and other underperforming practices) could often have been attributed to poor maintenance and poor initial location, as well as poor design, improper instillation, and unsuitable placement (Pitt 2003). He reported that the difference is in the robustness of the wet detention pond design, versus the dry detention pond.

The works by Stanley (1996), Nix and Durrans (1996), Bartone and Uchrin (1999), and Guo et al. (2000) were all additional references for dry detention pond research cited by Pitt (2003). These references cited studies that were not done on construction sites, indicating that they likely had lower contributing sediment loads. Stanley's work dealt with a 200-acre family residential contributing area in Greenville, NC and resulted in 42% to 83% reductions in suspended solids, with a mean of 68% out of eight storms (Stanley 1996). The last three sited references dealt with an off-line pond, a concrete versus vegetated facility, and outlet structure modifications, none of which dictated much similarity to removal efficiencies at a construction site (cited by Pitt 2003).

2.2.2 Sediment Basins

It is critical to assess construction site sediment basins independently of commercial or residential detention basins due to the variability of inputs and design between each practice. There has been variability over time in sediment basin design criteria, some aspects being permanent staples, others being added as new developments through advancements in research. Not all basins are the same, for efficiency, performance, and monetary reasons. The Highway Research Center out of Auburn, AL published a report detailing various highway department sediment basin usages and designs. Their intention was to acquire data from all fifty state department of transportations, but only thirty-seven responded to the survey. Out of thirty-seven responding state highway agencies, thirty-three had experience with using sediment basins and twenty-four of those had standard designs (Zech et al. 2012). When designing, nineteen of the thirty-three agencies used 2:1 as their minimum length to width ratio and twenty agencies did not have a maximum ratio. The length to width ratio is important in order to prevent short circuiting of the basin, which could cause preferential flow and not allow enough time for the sediment to settle. Regarding allowable slopes for the inflow channel, 61% of the agencies did not have a minimum slope and 67% did not have a maximum slope. Including Tennessee, thirteen agencies used flocculent additives to percolate out fine sediment particles. According to the survey, sixteen of the agencies used baffles inside of the basin, one of which being Tennessee. These baffles were most commonly made of silt fence material or coir fiber netting. The departments were surveyed on what dewatering devices they used: 70% used perforated riser pipes, 58% spillway only, 33% floating skimmer, 30% solid riser pipe, 12% flashboard riser pipe, and 15% other. The data indicated that only thirteen of the agencies used the floating skimmer outlet. Tennessee proved to be progressive in its use of flocculants, baffles, and skimmers (Zech et al. 2012).

In Pitt's work he (2003) explained that there is also a basin known as the extended detention pond, or combination pond. This is a pond that is normally dry but will have an outlet that causes the slow release of impounded water. This is what TDOT is referencing in their design as a sediment basin, especially with the use of a floating skimmer. In a study depicted by Taylor et al. in "Assessment of Costs and Benefits of Detention for Water Quality Enhancements" (2001), research was initiated by Caltrans in Los Angeles and San Diego, California, to monitor retrofitted extended detention facilities on existing highway sites. The result was an average suspended solids reduction of 73%. It was also estimated that removal of sediment build-up would need to occur every 10 years (cited by Pitt 2003).

Millen et al. (1997) evaluated alternative dewatering systems for sediment basins, including the assessment of the floating skimmer. The sediment used for their experiment was a silt loam. The skimmer reduced sediment values from 454 kilograms to 14.3 kilograms (96.8% retention) when passing through the basin for a 2-year return period storm simulation. The basin also retained 100% of the soil larger than 75 micrometer and 86 to 87% of the 6 to 12 micrometer particles (Millen et al. 1997). This study was done using controlled sediment inputs into the full sized sediment basin system.

McCaleb and McLaughlin (2008) assessed five basin devices on construction sites over various time periods of 5 to 13 months. Three of the basins had rock outlets and were designed for a 10-year storm with an alteration to the basic basin design that made each unique: 1) over excavated to have one meter of standing water, 2) silt fence baffles with weirs, and 3) open and fully drained. The fourth basin was similar to the third but designed for a 25-year storm. The fifth was designed for a 25-year storm, with a floating surface outlet, solid riser spillways, and porous baffles in the basin. The only device of the five of these that would be considered a sediment basin by TDOT design standards rather than a sediment trap is the fifth design with the skimmer outlet. The result of this study showed that the three 10-year storm sediment trap designs with rock dam outlets retained only <45% of the sediment that entered the sediment trap. In addition, the sediment basin with a skimmer, 2H:1V side slopes, and porous baffles retained up to 99% of the sediment that entered the basin. (McCaleb and McLaughlin 2008). The resulting water was still considerably turbid, indicating that very fine sediments would require another method to be removed, such as a flocculant, for example polyacrylamide (PAM) (TDEC 2012). It is also important to recognize the fact that over time the skimmer became bogged down with sediment and the efficiency was reduced significantly, indicating the importance of maintenance (McCaleb and McLaughlin 2008).

Fang et al. (2015) looked exclusively at one sediment basin design on a highway construction site in the article ‘Stormwater Field Evaluation and Its Challenges of a Sediment Basin with Skimmer and Baffles at a Highway Construction Site.” The basin layout is shown in Figure 2-4 and included a skimmer as the dewatering device, three baffles in the basin, PAM flocculant blocks, and ditch checks in the inflow channel. The results of this study showed that in the earlier stages of construction the basin removed 97.9 % and 83.7% of sediment generated on specific dates in November and December. It was noted that the influent likely contained higher percentages of large-sized sediment. It was also recognized that during high intensity storms the settled solids would become agitated again and cause a high level of turbidity in the basin, unrelated to what was coming in the inlet. In addition to collecting performance data, this report was useful for its summarized lessons learned. It was recommended from their research that the baffle height match or exceed full depth of the basin, as well as not be installed below minimum elevation of the emergency spillway. These recommendations would help keep the stormwater from overtopping the baffles and causing full mixing, negating the usefulness of the basin (Fang

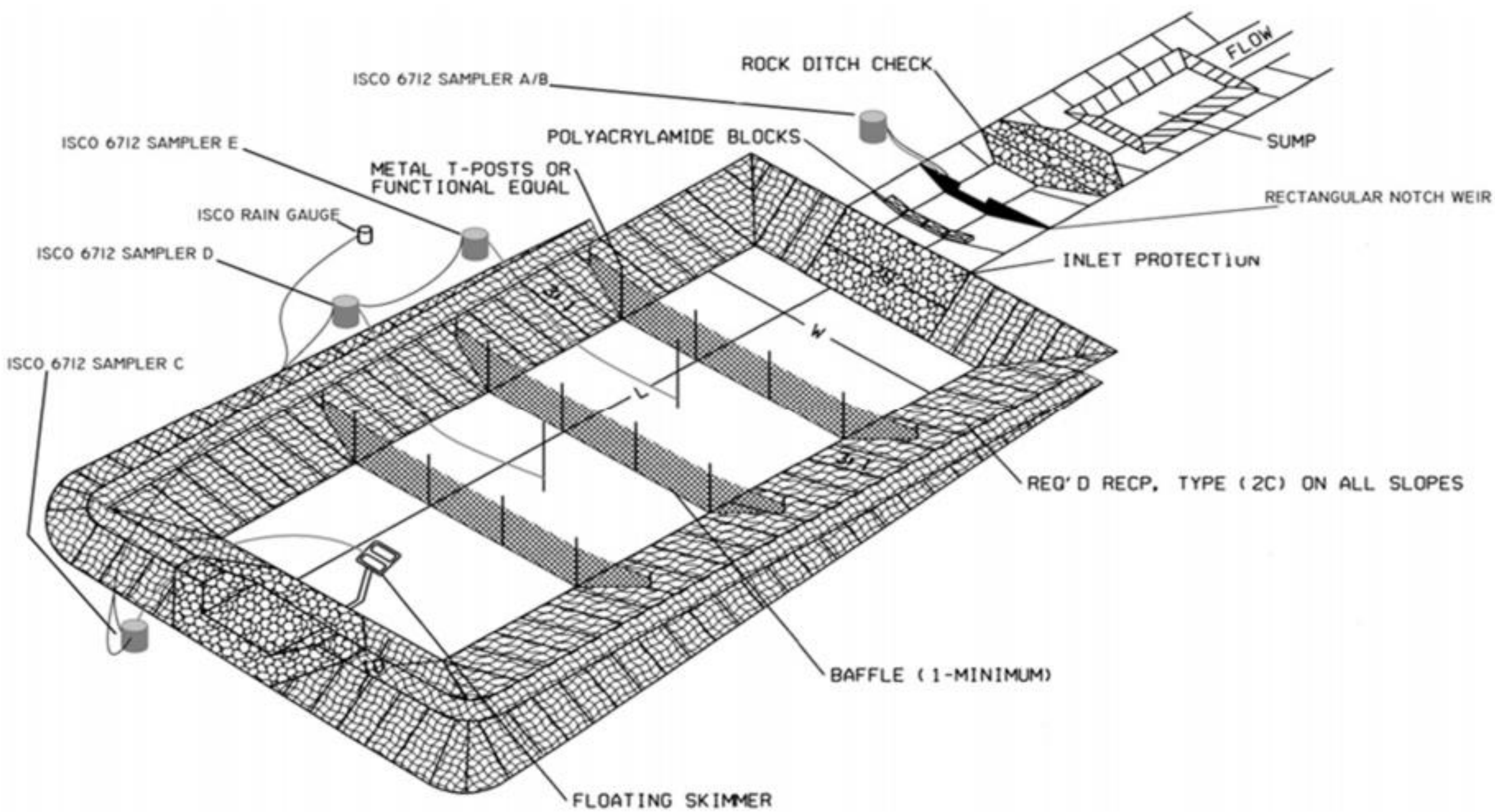

Figure 2-4. Design layout for experimental full-scale sediment basin with data collection equipment (Fang et al. 2015).

et al. 2015). It was clear from the recommendations section that it was imperative to communicate efficiently with the contractors installing the basin and ensure all aspects of it are installed correctly, making the design effective.

Fennessey and Jarrett (1994) detail the construction of a permanent sediment basin and development facility at Pennsylvania State University, which has since that time been used in multiple sediment basin studies. This basin was built with the variability of sediment inputs from urban and construction sites in mind. The intention of this basin was to be able to control multiple factors: inflow, inflow sediment concentrations, particle size distribution, detention times, and resuspension of sediment in the basin. The basin was sized to Pennsylvania standards for a 1-acre drainage area, 2-year 24-hour rainfall event. This resulted in a modified rectangular basin volume of 6,250 ft^3 with a plastic liner and changeable dewatering structure (Fennessey and Jarrett 1997). The controllability of this sediment basin lead to many other studies utilizing the structure to analyze variability between design aspects.

Apart from outlet device and risers, spillway design and permanent pool depth have the potential to affect sediment retention in sediment basins. Fennessey and Jarrett (1997) addressed this concept in their article "Influence of Principal Spillway Geometry and Permanent Pool Depth on Sediment Retention of Sedimentation Basins." Their research looked at 1) if the perforated riser principal spillway improved retention compared to a single-orifice, 2) whether an increase of 0.15 meters to 0.46 meters in the permanent pool depth would increase sediment retention, and 3) determine what portion of the basin's discharge was due to both resuspension in the basin and the physical degradation of the inner sides and bottom of the basin. Their results indicated that the difference in performance was nearly none between the perforated riser and single orifice. There was a difference in retention from the permanent pool depth, with a depth of 0.46 meters, the basin had 97.0% removal, where there was 94.7% removal at 0.15 meters. The research also showed that 11.0 kilograms of the 23.1 kilograms total discharged soil was from the influent, the remaining 22.1 kilograms was from 3.0 kilograms resuspended from previous events, and the remaining from scouring off the sides and bottom of the basin (Fennessey and Jarrett 1997).

In another study conducted by Madaras and Jarrett (2000), the full-sized construction basin from Fennessey and Jarrett's (1994) research was utilized to assess spatial and temporal distribution of sediment concentration and PSD in sediment basins. The results suggested that lined basins result in a 36% lower sediment concentration in the influent compared to unlined. This study also noted that the most likely sediment to resuspend was smaller particles due to their tendency to settle last in addition to their size and mass. The results noted that there also tended to be an average trend of smaller particles in the unlined system (Madaras and Jarrett 2000).

As indicated, there are a multitude of alterations that affect basin design; to the extent that established designs vary between all fifty states. The challenge is combining the variability between each design and addressing the optimally functioning design attributes. Through literature review it is clear that there is no single design for all scenarios. Various additions to a sediment basin will need to be made when unique factors persist. Perez et al. produced an extensive research report out of the Highway Research Center in Auburn, AL called “Design and Construction of a Large-scale Sediment Basin and Preliminary Testing Results”. This document’s summary tables (Table 2-3 and 2-4) provided a helpful literature summary of many various sediment basin alteration research results.

It is undoubtedly true that there has been a vast amount of perceptive research produced in regard to basins in general and a number of studies on monitored sediment basins. Publications have established that sediment basins are effective at removing larger sediment particles yet fall short of full removal via resuspension and inner basin scouring. These issues can be partially remediated by altering the design, such as adding baffles and ensuring there is a forebay. Implementing the use of a flocculant is another tool that can be added in the design, even detailing the way in which it is applied in the sediment basin (Fang et al. 2015). There is more to be learned by collecting data on basins with various design aspects through both natural and controlled precipitation events. Research falls short for highway construction sediment basin research, particularly the current Tennessee design. The following thesis research does not address every question; however, this thesis was designed to aid and encourage TDOT in using sediment basins when they are the best option and will aid as a tool in making them as effective as they can be with the knowledge that has been gained previously and with the following research.

Table 2-3. Part one literature review summary from the Highway Research Center in Auburn (Perez et al. 2015).

Study	Tested Parameters	Flow / Sediment Introduction	Data Collection Summary	Major Findings
Bhardwaj and McLaughlin 2008	physical and chemical treatments to control turbidity (i.e. baffles, active and passive PAM treatment), sediment basin (777 ft^3)	0.14 ft^3/s for 130 min, 1,543 lb. of sediment (settlement prior to introducing to test basin) 150 to 400 NTU	6 samplers @ 5 min. for NTU / TSS, bubbler mod. for spillway	active & passive PAM treatment reduced turbidity by 88%, active PAM treatment more effective at reducing TSS
Bhardwaj et al. 2008	sediment basin (777 ft^3): coir baffles, bottom inlet level spreader, PAM dosing	0.14 ft^3/s for 130 min, 1,543 lb. of sediment (settlement prior to introducing to test basin)	7 samplers @ 5 min. for NTU / TSS, bubbler mod. for spillway, clay mineralogy (x-ray diff. analysis), particle size dist. (hydrometer), baffle capture weights	reduced TSS by 45% to 65%
Bidelspach et al. 2004	sediment retention efficiency of delayed dewatering times on controlled sediment basin (5,000 ft^3)	3,531 ft^3 inflow hydrograph, 1000 lbs. of sediment	automated sampler at dewatering	sediment retention efficiencies for delayed dewatering of 0, 12, and 168 hrs resulted in 92, 94, and 98% capture effectiveness resp., infiltration contributed to dewatering
Engle and Jarrett 1995	sediment retention efficiency of filtered perforate riser outlets, lab scale basin (46.6 ft^3)	121 lbs of sediment	dewatering rates, sediment concentrations, sediment discharge rates, sediment retention efficiencies	no filter = 60-71% sediment retention, expanded polystyrene chips + 2-B gravel filter = 23-25% more effective
Griffin et al. 1985	dead storage characteristics of laboratory model using dye tracer tests	N/A	N/A	length to width ratios of 2:1 recommended for sediment basin design
Line and White 2001	trapping efficiency of sediment traps on construction sites in NC	natural storm events	water quality (total phosphorus, TSS, turbidity), sediment vol. via surveying, sediment analysis (hydrometer)	trapping efficiency ranged between 59 to 69%.
Logan 2012	trapping efficiency of sediment basin on construction site monitoring, 9.21 acre drainage basin @ 1,800 ft^3/acre	natural storm events	5 samplers, bubbler mod. for inflow, area velocity mod. for outflow, retained sediment analysis, baffle capture weights	correct selection of PAM critical to effective performance, resuspension evident after multiple events, basin volume should be increased to 3,600 ft^3/ac

Table 2-4. Part two literature review summary from the Highway Research Center in Auburn (Perez et al. 2015).

Study	Tested Parameters	Flow / Sediment Introduction	Data Collection Summary	Major Findings
McLaughlin et al. 2009	comparison of various design parameters (forebays, baffles, ditch stabilization, PAM, skimmers) on construction site sediment basins (~530 ft^3)	natural storm events	15 min. interval sampling for turbidity / TSS	water quality improvements by simple modifications, traps and skimmer did not contribute to improvement
Przepiora et al. 1997	compared efficiency of several calcium sulfate sources in reducing NTU of water samples collected from construction site sediment basins in NC	laboratory, bench-scale experiments	turbidity, pH, conductivity, and dissolved Ca	calcium sulfate applied at the rate of 350 to 700 mg/L reduced fine-grained suspended sediment in basins within 3 hours
Przepiora et al. 1998	evaluated the efficiency of calcium sulfate as a chemical flocculent in three construction site basins(1,590 to 5,830 ft^3) equipped with skimmer	natural storm events	100 mL grab samples from outlet	surface application of molding plaster significantly reduced both turbidity and the cumulative amount of suspended solids discharged
Thaxton and McLaughlin 2005	sediment basin (812 ft^3): vel. reduction by baffle types	0.50, 1.00, 1.50 ft^3/s	velocity at 50 points, bubbler mod. for flow rates	jute/coir and tree baffles most effectively diffuse inflow momentum

3.0 METHODS

3.1 Study Area

The intention of this study was to pick various sites with differing drainage areas, land slopes, and soil types. Two sites were selected in TDOT region one; these were selected in Morgan and Knox Counties. A third site was selected in region three, Bedford County, and is currently being monitored to contribute to TDOT's overall research goals on sediment performance. The three site locations in various parts of Tennessee are represented in Figure 3-1. This thesis summarizes the data from the Morgan and Knox County sites exclusively.

3.1.1 Morgan County

The Morgan County basin was designed for a roadway expansion project on Morgan County Highway in Harriman, Tennessee. The sediment basin captured a catchment drainage area of approximately 0.6 acres with a slope of approximately 10% (Figure 3-2). The catchment area contained a mix of two different soils: 1) a loam/gravelly clay loam formed from the parent material of fine-loamy alluvium derived from sandstone and shale and 2) a silt loam/clay loam formed from the parent material of fine-loamy residuum weathered from sandstone and shale (Soil Survey Staff n.d.). Effluent from the sediment basin at this site fed downstream into a series of rock check dams that transported water from the basin and the road down to Bitter Creek (Figure 3-3). During the duration of monitoring, active construction was predominantly done elsewhere on the project site, but the contributing catchment was left uncovered/bare in a pre-monitoring disturbed state. The drainage area was consistent and there was minimal additional soil disturbance throughout the monitored time frame. Six rainfall events were captured at this site, labeled event 6, 8, 9, 10, 14, and 15. Due to malfunctions in equipment, full event datasets were not always captured for consecutive storms.

3.1.2 Knox County

The Knox County basin was designed for a highway on-ramp design project in Knoxville, Tennessee, located at the intersection of North Broadway Street and I-640 (Figure D-1 and Figure D-2). This sediment basin captured a catchment drainage area of approximately 1.75 acres (Figure 3-4). The catchment slope varied but the main drainage way was approximately 3% to 5%. Apart from being classified as urban land, the soil was predominantly gravely silt loam, formed from a loamy residuum weathered from interbedded sedimentary ro

Figure 3-1. Map of locations for sediment basin monitoring sites across Tennessee.

Figure 3-2. Morgan County sediment basin drainage area and inlet H-flume.

Figure 3-3. Morgan County sediment basin outlet and downstream condition.

Figure 3-4. Knox County sediment basin drainage area and site layout.

(Soil Survey Staff n.d.). The basin effluent drained through a previously constructed rock check dam that surrounded a culvert. The culvert led from the construction area to Whites Creek and First Creek, which converged less than half a mile away from the site (Figure 3-5). The Knox County site often had construction inside the catchment area during the duration of monitoring, therefore, the characteristics of the catchment were shifting. No effort was taken to estimate these shifting values. Five rainfall events were captured at this site, labeled event 1, 2, 3, 5, and 6. Due to a malfunction in inlet equipment, a full dataset for event 4 was not captured.

3.2 Sediment Basin Design

Design criteria for sizing the basins was based off previous research by Neff and Schwartz in “Engineering Design Guidance for Highway Construction Sediment Basins” (Neff and Schwartz 2013). The sizes were determined using a theoretical minimum settling time associated with 100% silt removal (Table A-1). The original basin modeling sizes were done for a minimum area of 5 acres, both Morgan County and Knox County basins were smaller than 5 acres. The modeled basin sizes were linearly interpolated to achieve an appropriate size for the smaller drainage areas. Outlet skimmer device sizing, length to width ratio, and other necessary features were designed based on current standards in Chapter 10: Erosion Prevention and Sediment Control of the TDOT Drainage Manual (TDOT 2012). The manual suggested the sediment basins have a 4:1 length to width ratio and 2H:1V side slopes. The outlet dewatering structure was recommended to have a minimum pond dewatering time of 72 hours, which influenced the size of the orifice on the structure (Figure B-2). Standard skimmer sizing suggestions from J.W. Faircloth & Son Inc. were originally used for phase one (Table A-2). All values reflected the various slopes, drainage areas, soil types, and precipitation differences that were at the Morgan County and Knox County sites.

The final designed basin for Morgan County resulted in a length to width ratio of 2:1 and 2H:1V side slopes (Table 3-1). Due to corridor restrictions, the existing condition Morgan County basin was positioned such that its width was switched with its length. Resulting in a length to width ratio of 1:2 rather than 2:1 (Table 3-2). Final Knox County design dimensions indicated a length to width ratio of approximately 1:1.7 (Table 3-3). The existing condition Knox County basin was built to a length to width ratio of 1.2:1 (Table 3-4). The dimensions in Tables 3-1, 3-2, 3-3, and 3-4 use length to signify the measurement in the direction of inlet to outlet and width to signify the measurement perpendicular to length. When referenced, left and right

Figure 3-5. Knox County sediment basin outlet pipe and downstream condition.

Table 3-1. Morgan County sediment basin design dimensions (Figure C-1).

Morgan County Design Dimensions		
Quality	**Unit**	**Dimension**
Drainage Area	acres	0.6
Bottom Length	ft	30
Bottom Width	ft	19
Top Length	ft	47
Top Width	ft	36
Water Surface Elevation	ft	2.25
Top Elevation	ft	4.25

Table 3-2. Final Morgan County sediment basin existing condition dimensions, as measured on August 8th. 2017.

Morgan County Existing Conditions Dimensions		
Quality	**Unit**	**Dimension**
Drainage Area	acres	0.6
Bottom Length	ft	26
Bottom Width	ft	32
Top Length	ft	30
Top Width	ft	44
Top Elevation	ft	6

Table 3-3. Knox County sediment basin design dimensions (Figure D-3).

Knox County Design Dimensions		
Quality	**Unit**	**Dimension**
Drainage Area	acres	1.75
Bottom Length	ft	27
Bottom Width	ft	46
Top Length	ft	41
Top Width	ft	66
Water Surface Elevation	ft	3
Top Elevation	ft	5

Table 3-4. Final Knox County sediment basin existing condition dimensions, as measured on September 7th.

Knox County Existing Conditions Dimensions		
Quality	**Unit**	**Dimension**
Drainage Area	acres	1.75
Bottom Length (Left)	ft	37
Bottom Length (Right)	ft	46
Bottom Width (Front)	ft	34
Bottom Width (Back)	ft	36
Top Length (Left)	ft	53
Top Length (right)	ft	64
Top Width (Front)	ft	62
Top Width (Back)	ft	61
Top Elevation	ft	7

indicate facing away from the inlet towards the outlet; front indicates the width at the inlet and back indicates the width at the outlet.

3.3 Water-Sediment Monitoring and Collection Equipment

3.3.1 Morgan County

This sediment basin was equipped at the inlet with a 1-foot Tracom© H-flume, stage recording device, ISCO® 3700 Portable Sampler, and ISCO® 4230 Flow Meter. The H-flume was outfitted with a 6-inch diameter stilling well in order to use a HOBO U20L Series Water Level Logger stage recording device. This device recorded water pressure and temperature once every minute in the stilling well, which was open to the flume by a 1-inch hole at the base of the flume. There was an identical device open to atmosphere to account for barometric pressure changes and was used to calculate the flume water levels. The H-flume was also equipped with treated plywood wing walls and a level 2-foot-long concrete entry pad. The concrete pad was positioned directly past the exposed soil slopping down from the catchment area. The ISCO® 3700 Portable Sampler tubing was secured facing upstream on a slopes half-pipe directly after the free flow coming from the H-flume. This system was triggered by an ISCO 4230 Flow Meter, whose tubing was fixed in the stilling well with the HOBO Water Level Logger. The full inlet system is depicted in Figure 3-6. The flow coming off of the half-pipe ISCO collection location flowed freely into an estimated 6 to 8-foot class A-1 rip rap inlet (2 to 15-inch diameter).

The outlet for this site was equipped with an improved flow divider bucket system designed by colleagues in the University of Tennessee's Biosystems Engineering and Soil Science Department, shown in Figure 3-7. The improved flow divider bucket system was utilized because of its independence from electronic failure, an issue that is common in field research. This monitoring design was not utilized at the inlet due to the lack of drop directly preceding the basin in addition to the likelihood that high levels of sediment would overwhelm the buckets and lessen the data accuracy. The outlet monitoring system was designed based on recommendations from Pinson et al. (2004), an estimated total maximum water volume calculation coming out of the system, available material, and a limitation on vertical drop from the outlet pipe. The system was composed of 5-gallon buckets with flow dividers that contained a stainless-steel crown with various numbers of 22.5° V-notch weirs machined into it. The crown was water sealed to allow flow exclusively through the V-notch and screwed onto a 5-gallon bucket. The bucket directly

Figure 3-6. Morgan County sediment basin inlet monitoring flume and accompanying materials.

Figure 3-7. Morgan County sediment basin outlet monitoring buckets, stand, and leveling device.

under the 90-degree 6-inch PVC outlet was chosen to handle higher flow rates with twelve V-notches around the rim to split flows evenly. This bucket handled up to 1.05 cfs, had a flow rate of 0.088 cfs per slot, and a 6-inch slot height. The following two buckets were designed to split flows at an optimal higher number of splits and contained twenty-four V-notches each around the rim. These buckets handled up to 0.24 cfs of flow, had a flow rate of 0.01 cfs out of each slot, and a 2.5-inch height for each slot. The last bucket did not have a crown. The system worked such that once one bucket was filled, water and sediment would be divided evenly among the V-notches and the flow from one such notch would be directed to the next bucket. These buckets were secured to a metal triangular leveling device and were checked for proper level after each event. The leveling triangles were secured via the tightening bolts to a sturdy, treated wooden frame built specifically for this purpose.

3.3.2 Knox County

The second site in Knox County had a similar inlet monitoring design to Morgan County, including similar limitations to using the improved flow divider bucket system at the inlet. This site was equipped at the inlet with a 1.5-foot Tracom© H-flume, stage recording device, ISCO® 4230 Flow Meter, and an ISCO® 3700 Portable Sampler. The H-flume was outfitted with a stilling well and used a HOBO U20L Series Water Level Logger, as well as a second water level logger open to atmosphere, recording once every minute. The H-flume was equipped with treated plywood wing walls and a level 2-foot-long concrete entry pad. This concrete pad was placed directly after an 8 to 10-foot segment of class A-1 rip-rap. The ISCO® 3700 Portable Sampler tubing was secured facing upstream on an angled half-pipe directly after the free flow coming off the H-flume. This system was triggered by an ISCO® 4230 Flow Meter, whose tubing was fixed in the stilling well with the HOBO Water Level Logger. The full inlet monitoring system is depicted in Figure 3-8.

The original design for the outlet was going to be similar to the Morgan County site; however, once the basin was built there was very little vertical drop to where the buckets could be placed, so an alternate design was implemented. Instead of the bucket system, a 90-degree V-notch weir was used at the outlet of the sediment basin. This was sized for maximum flow out of a 6-inch pipe, due to the outlet structure being a steady flow skimmer. The weir box was 45 inches wide, 34 inches deep, and 18 inches tall. It included a baffle located half way along its depth that had 4 inches of free space below it for water to pass through (Figure 3-9). The metal

Figure 3-8. Knox County sediment basin inlet monitoring flume and accompanying materials.

Figure 3-9. Knox County sediment basin outlet 90-degree V-notch weir box and outlet pipe.

V-weir was 15 inches tall, 30 inches wide at its top, and had 3 inches of space below its tip. The water level was recorded in the weir box using a third HOBO U20L Series Water Level Logger. Samples were taken using a second ISCO® 3700 Portable Sampler with the tubing inserted at the bottom of the 6-inch outlet pipe using a fitting (Figure 3-10). The sampler was triggered by a ISCO 4230 Flow Meter whose tubing was located in the bottom of the weir box secured to the water level logger housing.

3.3.3 Weather Station Equipment

As intended in the original proposal, a fully equipped weather station was installed at both Morgan and Knox County. Each station included a Davis® 0.01” Rain Gauge Smart Sensor, 12-bit Temperature/Relative Humidity Smart Sensor, Solar Radiation Shield Wind Speed Smart Sensor, and a 6W Solar Panel (Figure 3-11). Morgan County was equipped with the HOBO RX3000 Remote Monitoring Station Data Logger and used a cellular plan to remotely check weather station data and sensors. Knox County was equipped with a HOBO U30 USB Weather Station Data Logger that data could be manually retrieved from using a USB cable and the program HOBOLink Pro.

The weather equipment took readings every 5 minutes to ensure enough data was taken to be representative of changing weather conditions in the area. The manual rain gauge was used as a backup to check the tipping bucket rain gauge values. The tipping bucket rain gauge readings were used multiple times in the study. These values helped to define event periods and the beginning and end of flow events through the flume to help correct for sediment laden water pressure influence in the pressure transducer. The precipitation values were also used in the sediment yield modeling calculations of RUSLE2 to find each event’s 30-minute intensity and thus contributed to the rainfall erosivity factor. The temperature, relative humidity, and wind speed were not used in this study, yet could be used in future studies/analysis and were promised monitored variables in the original field monitoring portion of the project proposal.

3.4 Flow Analysis at Inlet and Outlet

3.4.1 Flume Stage Discharge Relationship

In order to quantify the flow coming into the inlet of the sediment basin a stage-discharge relationship was utilized to build a hydrograph for each storm period sampled. The high amount of sediment contributing to the basin from off the catchment slope and depositing in the floor of the flood could have influenced aspects of the rating curve. There was no alteration of the flow

Figure 3-10. Alternate view of outlet monitoring device at Knox County, includes ISCO® 3700 Portable Sampler, tubing, and bubbler housing.

Figure 3-11. Knox County sediment basin weather monitoring set-up, includes data logger, tipping bucket rain gauge, temperature/relative humidity sensor, wind speed sensor, solar panel, manual rain gauge, and atmospheric pressure transducer.

values to account for this. The stage-discharge for Morgan County was found using the following formula for a 1-foot Tracom© H-flume with H being head in meters and Q being flow in m^3/s:

$$logQ = 0.0206 + 2.5902logH + 0.2281(logH)^2$$

The resulting values were then converted to cfs. The stage-discharge for Knox County was found using the following formula for a 1.5- foot Tracom© H-flume with H being head in meters and Q being flow in m^3/s:

$$logQ = 0.0238 + 2.5473logH + 0.2540(logH)^2$$

The resulting values were then converted to cfs.

3.4.2 Flow Divider Bucket System Volume Relationship

At the Morgan County site, outlet volumes were determined by first measuring the water depth in each bucket after a sampling period. When the bucket was full, the water volume in the calculation was considered to be the entire approximately 5-gallon volume. When the bucket was partially full, the volume in the bucket was calculated from taking the partial depth and other dimensions of the bucket. Calculating the total outlet volume required multiplying each full bucket by twelve or twenty-four, depending on how many notches that bucket had on its ring. Summing those values together plus an additional 5 gallons of water for the first fill, produced the maximum monitoring system volume. If the event did not completely fill up all four buckets, the measured non-full bucket(s) volume(s) were incorporated into the measurement and subtracted out (with its v-weir multiplier considered). Evaporation was neglected. Furthermore, buckets that had clean rainwater exclusively were not included in the calculation and rainwater depth was taken out of the volume measurement for each full bucket.

3.4.3 V-notch Weir Discharge Relationship

At the Knox County site, outlet volumes were determined using standard calculations of monitored depth converted to flow measurements from a 90° V-notch weir. The following formula was utilized:

$$Q = \frac{8}{15} C_{de} \sqrt{2g} \tan\frac{\theta}{2} H_e^{\frac{5}{2}}$$

The variable Q represents flow in m^3/s, g represents gravity in m/s^2, and the variable θ represents the angle of the V-notch, which in this case is 90-degrees. The variable C_{de} is the coefficient of discharge, which is a value used in the Kindsvater-Carter form of the V-notch discharge equation.

In order to find C_{de}, the following equations were checked to ensure fully contracted flow:

$$\frac{H}{P} \leq 0.4 \quad and \quad \frac{P}{b} \leq 0.2$$

The variable H represents height of water above the tip of the V-notch in meters and P represents the fixed height from the tip of the 90-degree notch down to the bottom of the weir box; this value is 76.2 x 10^{-3} meters. The variable b is representative of the width of the weir box, in this case 1.2 meters. The variables are depicted in Figure 3-12.

Once these variables were found, if the previous equations were confirmed, making the scenario fully contracted, the equation L/b would need to be found and plugged into Table 3-5 by Kindsvater and Carter 1957 to find the coefficient of discharge. If the scenario was only partially contracted, Figure 3-13 would be used to find coefficient of discharge. In both scenarios of partially contracted and fully contracted flow, H_e represents effective head in meters, or H + k_h. The variable k_h is the head correction value in meters and is found using Figure 3-14. All values for flow were converted from metric to imperial units of cfs.

3.5 Sediment Load Analysis

3.5.1 Suspended Sediment Concentration

The air-drying method for suspended sediment concentration (SSC) was utilized to quantify sediment concentrations in the collected inlet and outlet water samples. All samples taken at the inlet for one event were combined to result in one inlet concentration measurement. The same was done for each event's outlet samples. This reflected in one sample for inlet water and one sample for outlet water for each sampling event, rather than multiple that would reflect various sediment values over time. This was done due to the mechanical complications and unreliability of sampling at the inlet. Each sample volume was taken and deposited into a drying dish. These samples were then dried using forced air drying over a period of 3 to 5 days. Once dry, the resulting sediment was weighed to quantify concentrations in g/L. These values were then assumed to be the average concentration for the duration of the storm. Total mass at the inlet was calculated by using the concentration and the flume stage discharge relationship outlined previously. Total mass at the outlet in Morgan County was found by pairing the flow divider bucket volume calculation and the concentration. Total mass at the outlet in Knox County was

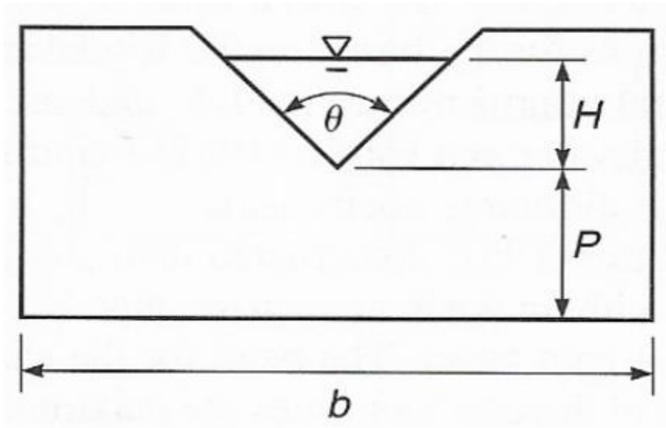

Figure 3-12. V-notch weir variable definitions (Sturm 2010).

Table 3-5. Coefficients of discharge for the Kindsvater-Carter formula (Sturm 2010).

L/b	C_{de}
1	0.602 + 0.075 H/P
0.9	0.599 + 0.064 H/P
0.8	0.597 + 0.045 H/P
0.7	0.595 + 0.030 H/P
0.6	0.593 + 0.018 H/P
0.5	0.592 + 0.011 H/P
0.4	0.591 + 0.0058 H/P
0.3	0.590 + 0.0020 H/P
0.2	0.589 – 0.0018 H/P
0.1	0.588 – 0.0021 H/P
0	0.587 – 0.0023 H/P

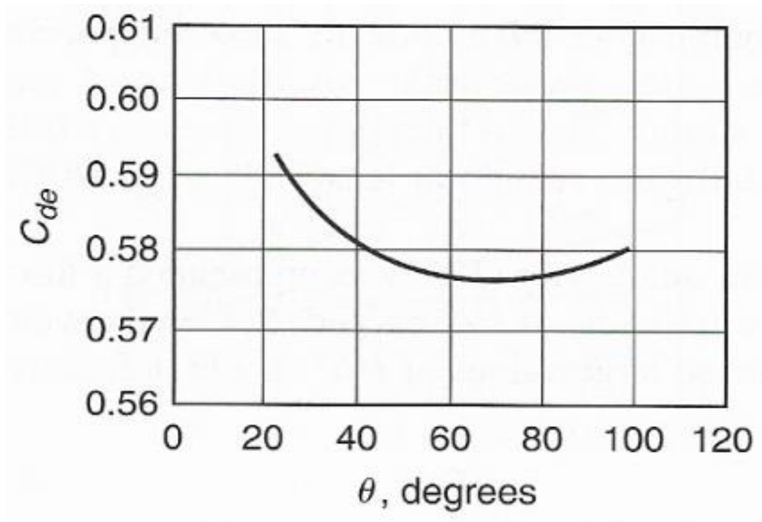

Figure 3-13. Coefficient of discharge for 90-degree V-notch weirs partially contracted flow (Sturm 2010).

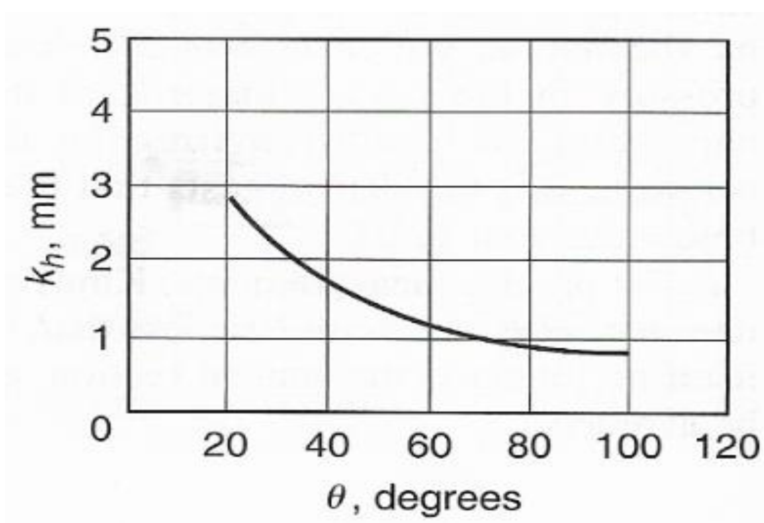

Figure 3-14. Head correction for 90-degree V-notch weirs partially contracted flow (Sturm 2010).

calculated using the 90-degree V-notch weir discharge relationship and the calculated average concentration.

3.5.2 Approach Area Deposit Samples

The sediment deposited in the flume and on the concrete approach pad was also estimated to assist in quantify the total sediment amount coming off of the catchment area upslope of the inlet flume and basin. This area/soil is referred to throughout the thesis as the approach area or approach area soil or approach soil. These values were not used when determining the performance of the basin. After each sampling event, the average depth of sediment accumulation in the flume and concrete entryway was recorded. A consolidated and thoroughly mixed sample was then taken in a 1-gallon bag, filled an estimated 75% of the way full. The remaining deposited soil was cleaned from the flume, off the concrete pad, and out of the end of the approach channel and deposited far enough away from the monitoring site so as not to contribute to the basin system. The collected sample was taken back to the laboratory and dried to get a rough mass. This mass was then divided by the volume to get a concentration. The concentration was then multiplied by the estimated volume taken from the approach area and depth of sediment from the sampling period. This resulted in an estimated mass in kilograms of soil deposited in the approach area.

3.6 Particle Size Distribution

3.6.1 Sieve Analysis

To understand the composition of sediment in the system, the first step was to sieve the samples. This included suspended sediment from inlet and outlet water samples, as well as flume soil deposits, sediment basin soil deposits, and three samples taken from the runoff area upslope of the basin. Post drying, the samples were crushed using a mortar and rubber pestle, enough to break up caking, yet not enough to diminish the integrity of the larger particles in the sample. Next, the samples were dry sieved through a 2.0-millimeter (No. 10) sieve. This resulted in a sample that no longer contained larger than sand particles. After larger particles were sieved out, each sample was wet sieved through a 0.074-millimeter (No. 200) sieve. These samples were dried and weighed again to show the amount of sand versus silt and clay still left in the samples (ASTM 2017).

3.6.2 Laser Diffraction Particle Size Analysis

Each sample, once sieved for sand and larger particles, was then prepared for use in a laser diffraction particle size analyzer. Preparing each exclusively silt and clay sample began by using a two-splitter riffle divider multiple times to pair the sample down to 2 grams of soil. This reduced sample was then resuspended in 15 milliliter tubes using 4 grams of a standard 40 g/L sodium-hexametaphosphate solution and left for a minimum of 24 hours to allow disaggregation of clay particles.

Once all previous steps had been completed, the Beckman Coulter LS 13 320 Laser Diffraction Particle Size Analyzer was utilized. The sample handling option utilized was the Universal Liquid Module (ULM). Each sample was mixed in the test tubes by constantly pipetting the liquid/sediment mixture using disposable plastic pipettes. The sample was then deposited into the ULM, which in addition to containing the sample, was constantly sonicating. To begin, a test sample was run three times to compare grab accuracy. Once it was ensured that the accuracy of a grab could be replicated, each sample was run one time. This resulted in very detailed information on the percentages of clay and silt in the samples.

3.7 Statistical Analysis for Basin Performance

Both Morgan County and Knox County mass and SSC concentration inlet and outlet data were analyzed using the goodness-of-fit Shapiro-Wilk W test to check for normality. The data was also visually checked for normality. If the analysis did not result in a normal trend, the data was logarithmically transformed. All data was established as normal, log-transformed and un-transformed, thus a paired t-test was used to compare the inlet to the outlet. The matched pair test was used to assess the significant difference between the inlet and outlet sediment masses and concentration values. This analysis was done using JMP Pro 14.

3.8 Sediment Yield Modeling

3.8.1 RUSLE2 Modeling

RUSLE2 Version 2.6.10.4 (December 19th, 2017) was used to compare modeled soil loss from catchment slopes to field validated masses. The field validated mass refers to the sum of approach area sediment mass and inlet water sample sediment mass. It is acknowledged that RUSLE2 does not account for the channelized flow that likely occurred in part of the catchment area being analyzed. This investigation contributed to the understanding of how using the modeling software RUSLE2 aids in characterizing soil loss from drainage slopes on TDOT construction sites, resulting in estimated sediment storage design values for sediment basins.

The soil type assessed from field and laboratory results was used in RUSLE2 modeling as the soil input. The percent of soil cover was estimated for each site based on visual estimation. To represent the construction sites, the management selected was highly disturbed\bare\bare cut and the operation selected was no operation. The topography, length and slope of the site was estimated from GIS assessment. The rainfall data set was taken from the six representative storms at Morgan County and the five representative storms at Knox County. The rainfall data values inputted were rainfall depth (inches), erosivity, duration (hours), and max interval intensity (in/hr) (30-minute maximum intensity).

4.0 RESULTS

4.1 Catchment Soils Particle Size Distribution

Three soil samples were taken from the upland catchment soil at both sampling sites. These samples were taken on the last collection day of sampling. The first sample (UP-1) was taken furthest away from the sampling flume and basin. The third sample (UP-3) was taken just above the sampling flume and basin before any major sediment deposition had occurred. The second sample (UP-2) was taken between the first and third, approximately equal distance.

All three Morgan County catchment soils were classified as silt loams. The mean values for percent particle size were as follows: gravel 7.2%, sand 16.9%, silt 67.8%, and clay 8%. Individual sample particle size percentage results for Morgan County catchment soils are summarized in Table 4-1.

All three Knox County catchment soils were classified as gravely sandy loams, with the first sample classified as an extremely gravely and the other samples as very gravely. The mean values for percent particle size were as follows: gravel 56.2%, sand 27.5%, silt 15.2%, and clay 1.1%. Individual sample particle size percentage results for Knox County catchment soils are summarized in Table 4-2.

4.2 Approach Area Soil Deposition and Storm Intensity

At Morgan County, the depth of deposited sediment in the approach area varied between 3.5 inches and 5.0 inches, with an average of 4.3 inches. The volume deposited varied between 35.1 kilograms and 52.1 kilograms, with an average of 41.3 kilograms. Table 4-3 summarizes the approach area deposit depths and extra soil mass for all six captured events at the Morgan County basin. At Knox County, the depth of deposited sediment in the approach area varied between 1.5 inches and 5.0 inches, with an average of 3.3 inches. The volume of deposited soil varied as well, between 13.7 kilograms and 52.8 kilograms, with an average of 35.5 kilograms. Table 4-4 summarizes the approach area deposit depths and extra soil masses for all five captured events at the Knox County basin.

The 30-minute rainfall intensity values are detailed in Table 4-5 for the Morgan County construction site. The values ranged from 0.50 to 2.20 in/hr, with an average rainfall intensity of 1.10 in/hr and a median of 0.80 in/hr. Knox County 30-minute rainfall intensity values are displayed in Table 4-6. The values ranged from 0.30 to 1.14 in/hr, with an average rainfall intensity of 0.48 in/hr and a median of 0.57 in/hr. Figure 4-1 compares rainfall intensities as th

Table 4-1. Morgan County soil sample classification of upland soil from catchment area.

Sample	Soil Classification	Percent Gravel 2 mm +	Percent Sand < 2 mm & > 0.074 mm	Percent Silt < 0.074 mm & > 0.002 mm	Percent Clay < 0.002 mm
UP-1	**Silt Loam**	6.8	21.4	63.7	8.1
UP-2	**Silt Loam**	7.9	18.2	66.4	7.5
UP-3	**Silt Loam**	7.0	11.2	73.4	8.4

Table 4-2. Knox County soil sample classification of upland soil from catchment area.

Sample	Soil Classification	Percent Gravel 2 mm +	Percent Sand < 2 mm & > 0.074 mm	Percent Silt <0.074 mm & >0.002 mm	Percent Clay <0.002 mm
UP-1	**Extremely Gravely Sandy Loam**	77.1	16.3	6.1	0.5
UP-2	**Very Gravely Sandy Loam**	35.2	30.0	24.2	1.6
UP-3	**Very Gravely Sandy Loam**	56.4	27.1	15.4	1.2

Table 4-3. Morgan County approach area deposit depths and masses.

Event #	Flume Deposit Depth (in)	Inlet Soil Mass (kg)
6	5.0	49.0
8	4.0	38.0
9	4.5	35.1
10	5.0	52.1
14	3.5	35.9
15	4.0	37.9

Table 4-4. Knox County approach area deposit depths and masses.

Event #	Flume Deposit Depth (in)	Inlet Soil Mass (kg)
1	5.0	52.8
2	3.0	41.3
3	4.0	42.0
5	1.5	13.7
6	3.0	27.9

Table 4-5. Morgan County 30-minute rainfall intensities.

Morgan County	
Sampling Event #	**30-min intensity (in/hr)**
6	2.2
8	0.68
9	0.92
10	1.72
14	0.6
15	0.5

Table 4-6. Knox County 30-minute rainfall intensities.

Knox County	
Sampling Event #	**30-min intensity (in/hr)**
1	1.14
2	0.5
3	0.48
4	0.3
6	0.42

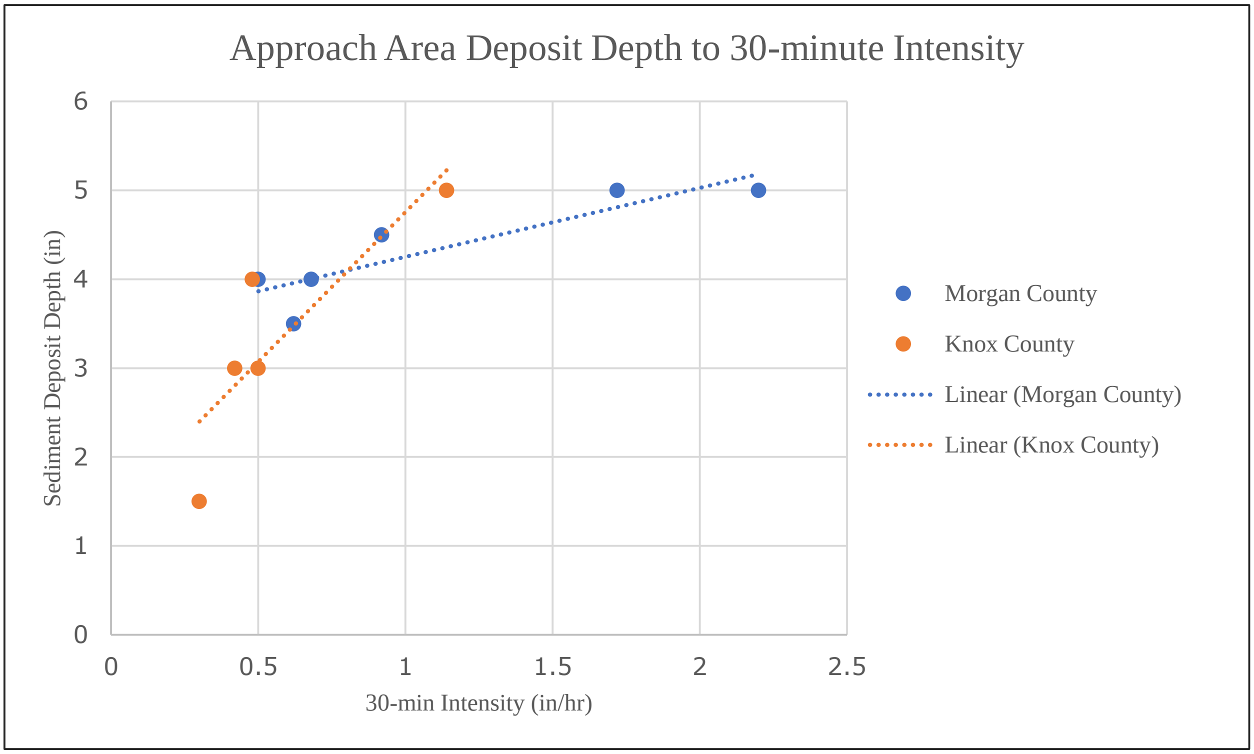

Figure 4-1. Morgan County and Knox County approach area deposit depth to 30-minute intensity comparison and trend.

independent variable with approach area deposited depth as the dependent variable. The results showed a linear trend between intensity and deposition depth; the higher intensity storm, the greater amount of soil detachment, which resulted in higher amounts of deposited soil in the approach area.

4.3 Particle Size Distribution Comparison

The particle size data was analyzed for Morgan County, assessing inlet plus approach area, basin deposit, and outlet average individual particle size mass values. Inlet and approach sediment average values were combined to better quantify sediment loss from the catchment area being routed to the basin. Morgan County basin sample estimated total mass was found by subtracting the total mass of outlet from the total mass of the inlet for event 15, the event for which a basin sediment sample was taken. All three particle size mass values were found by multiplying the total mass of the contributing section by the percentage of each particle size was in the sample. The percent reduction of various particle sizes was analyzed; there was a 100% reduction in gravel, 99.2% reduction in sand, 72.4% reduction in silt, and 72.7% reduction in clay (Table 4-7).

Identical analysis was implemented for the Knox County data. The Knox County basin sample estimated total mass was found by subtracting the total mass of the outlet from the total mass of the inlet for event 6, the event for which the basin sediment sample was taken. The percent reduction of various particle sizes was assessed; there was a 100% reduction in gravel and 99.9% reduction in sand, silt, and clay (Table 4-8).

In depth inlet and outlet comparison between PSD mass values was analyzed for Morgan County (Table 4-9). Morgan County inlet gravel masses ranged between 2.6 kg and 119.4 kg with an average of 45.7 kg, where the outlet contained 0 kg of gravel. The sand inlet values ranged from 38.7 kg to 1449 kg, with an average of 553.0 kg, where the outlet ranged from 0.8 kg to 9.4 kg, with an average of 4.6 kg. The silt inlet mass values ranged from 189.0 kg to 2281.4 kg, with an average of 1210.9 kg, where the outlet values ranged from 4.1 kg to 693.4 kg, with an average of 341.1 kg. The clay inlet quantities ranged from 24.6 kg to 279.6 kg, with an average of 125.8 kg, and the outlet ranged from 1.3 kg to 69.2 kg, with an average of 34.9 kg. Figure 4-2 shows the Morgan County average inlet and outlet PSD percentages in pie charts to visually depict the changes in particle size composition undergone between the two sample locations.

Table 4-7. Morgan County inlet plus approach mass, basin mass, and outlet particle classification mass values in kilograms.

	Average Individual Particle Size Mass Values (kg)			
	Inlet + Approach	**Basin**	**Outlet**	**Percent Reduction (Inlet + Approach to Outlet)**
Gravel	47.4	142.5	0.0	**100.0**
Sand	561.4	682.0	4.6	**99.2**
Silt	1233.5	1591.6	341.1	**72.4**
Clay	128.1	161.6	34.9	**72.7**

Table 4-8. Knox County inlet plus approach mass, basin mass, and outlet particle classification mass values in kilograms.

	Average Individual Particle Size Mass Values (kg)			
	Inlet + Approach	**Basin**	**Outlet**	**Percent Reduction (Inlet + Approach to Outlet)**
Gravel	17.5	2.5×10^{-3}	0.0	**100.0**
Sand	13.4	0.3×10^{-3}	0.4×10^{-6}	**99.9**
Silt	4.4	2.7×10^{-3}	70.3×10^{-6}	**99.9**
Clay	0.3	0.2×10^{-3}	5.1×10^{-6}	**99.9**

Table 4-9. Morgan County inlet and outlet particle size distribution mass values in kilograms.

	Mass Gravel (kg) 2 mm +		Mass Sand (kg) < 2 mm & > 0.074 mm		Mass Silt (kg) <0.074 mm & >0.002 mm		Mass Clay (kg) <0.002 mm	
Event #	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**
6	119.4	0.0	1449.0	0.1	2002.7	245.8	194.3	18.2
8	87.0	0.0	635.3	3.6	1362.8	335.9	134.0	32.9
9	22.5	0.0	276.0	6.5	927.7	424.9	69.0	57.8
10	7.7	0.0	168.0	9.4	501.6	342.3	53.0	30.3
14	2.6	0.0	38.7	0.8	189.0	4.1	24.6	1.3
15	35.1	0.0	751.0	6.9	2281.4	693.4	279.6	69.2
Average:	**45.7**	**0.0**	**553.0**	**4.6**	**1210.9**	**341.1**	**125.8**	**34.9**

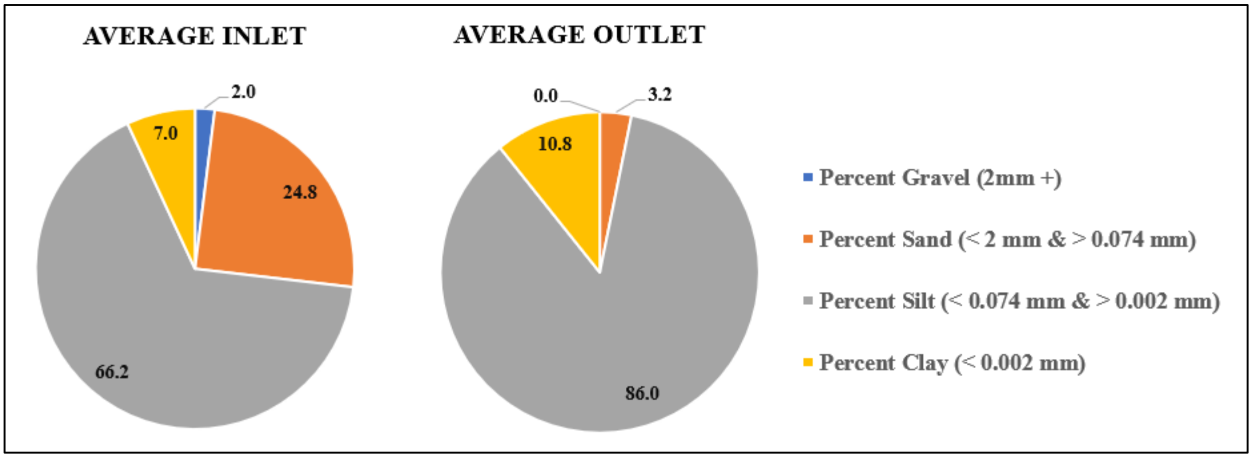

Figure 4-2. Morgan County inlet and outlet particle size distribution percentage pie charts; inlet values are from inlet water samples only, does not include approach channel deposition.

Detailed inlet and outlet PSD mass comparison was implemented on Knox County sediment data (Table 4-10). Knox County inlet gravel masses ranged between 0 kg and 7.2 x 10^{-6} kg, with an average of 1.4 x 10^{-6} kg, where the outlet contained 0 kg of gravel. The sand inlet values ranged from 0 kg to 323.4 x 10^{-6} kg, with an average of 82.4 x 10^{-6} kg, where the outlet ranged from 0 kg to 1.9 x 10^{-6} kg, with an average of 0.4 x 10^{-6} kg. The silt inlet mass values ranged from 162.4 x 10^{-6} kg to 5,171.7 x 10^{-6} kg, with an average of 1,362.6 x 10^{-6} kg, where the outlet values ranged from 1.7 x 10^{-6} kg to 320.7 x 10^{-6} kg, with an average of 70.3 x 10^{-6} kg. The clay inlet quantities ranged from 17.7 x 10^{-6} kg to 555.9 x 10^{-6} kg, with an average of 143.9 x 10^{-6} kg, and the outlet ranged from 0.2 x 10^{-6} kg to 21.4 x 10^{-6} kg, with an average of 5.1 x 10^{-6} kg. Figure 4-3 shows the Knox County average inlet and outlet PSD percentages in pie charts to visually depict the changes in particle size composition undergone between the two sample locations.

4.4 Sediment Basin Performance

To understand performance of the basin, total mass difference was analyzed for the inlet and outlet. This value did not include sediment deposited in the approach area. At the Morgan County site, the mass percent retained in the basin had an average of 76.8%, with a range between 47.7% and 97.5% mass reduction. The data also had a median of 80.1% and a standard deviation of 18.9%. The data was found to be normally distributed with a large p-value of 0.7232 and a small sample size. The SCC average reduction was 72%, with a range between 13.0% and 95.8% reduction. Table 4-11 shows summary data for the percentage mass retained in the basin based on inlet and outlet values for Morgan County, as well as SCC reduction percentages, time, and precipitation information for the events.

An event matched pair analysis was run on the Morgan County mass and SCC values for the inlet and outlet. The data passed the normality test and a paired t-test was utilized. When comparing sediment mass values from inlet to outlet at Morgan County, the t-ratio was -2.89 with a degree of freedom of 5. The mean difference between the inlet and outlet masses was -1.6 x 10^3 kilograms. The resulting p-value of 0.0342 was less than the alpha of 0.05 (95% significance level), indicating the null hypothesis was rejected and the inlet and outlet mass values were significantly different. When sediment concentration inlet and outlet values were compared, the t-ratio was approximately -2.20 with a degree of freedom of 5. The mean difference between the inlet and outlet concentrations was -49.9 g/L. The p-value of 0.0793, greater than an alpha of 0.05, indicated the rejection to fail the null hypothesis and the inlet and

Table 4-10. Knox County inlet and outlet particle size distribution mass values in kilograms.

	Mass Gravel (kg) 2 mm +		Mass Sand (kg) < 2 mm & > 0.074 mm		Mass Silt (kg) <0.074 mm & >0.002 mm		Mass Clay (kg) <0.002 mm	
Event #	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**
1	7.2×10^{-6}	0	28.1×10^{-6}	0.1×10^{-6}	182.1×10^{-6}	7.1×10^{-6}	18.6×10^{-6}	0.8×10^{-6}
2	0	0	58.6×10^{-6}	0	$1{,}005.4 \times 10^{-6}$	19.4×10^{-6}	91×10^{-6}	2.6×10^{-6}
3	0	0	1.9×10^{-6}	0	162.4×10^{-6}	2.8×10^{-6}	17.7×10^{-6}	0.2×10^{-6}
5	0	0	0	0	291.5×10^{-6}	1.7×10^{-6}	36.5×10^{-6}	0.3×10^{-6}
6	0	0	323.4×10^{-6}	1.9×10^{-6}	$5{,}171.7 \times 10^{-6}$	320.7×10^{-6}	555.9×10^{-6}	21.4×10^{-6}
Average:	**1.4×10^{-6}**	**0**	**82.4×10^{-6}**	**0.4×10^{-6}**	**$1{,}362.6 \times 10^{-6}$**	**70.3×10^{-6}**	**143.9×10^{-6}**	**5.1×10^{-6}**

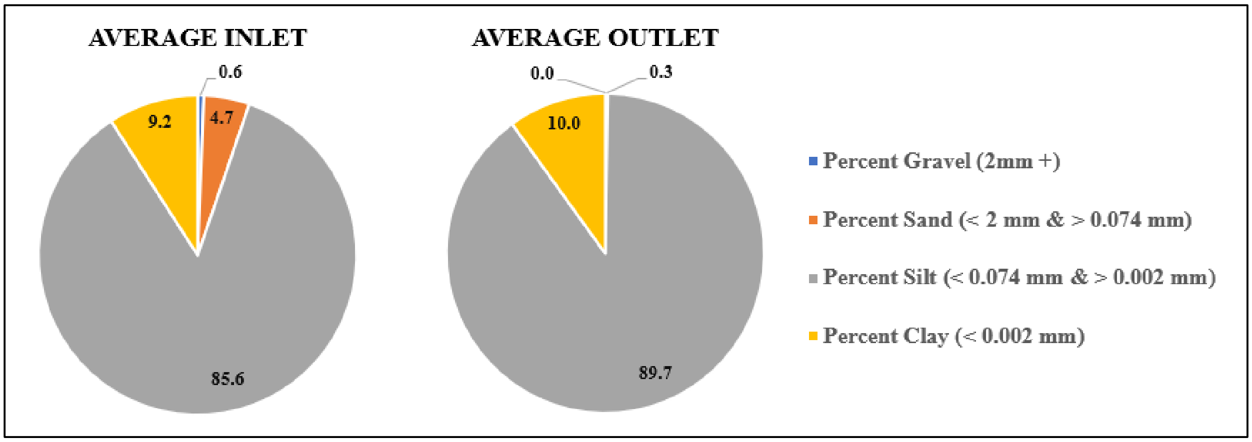

Figure 4-3. Knox County inlet and outlet particle size distribution percentage pie charts; inlet values are from inlet water samples only, does not include approach channel deposition.

Table 4-11. Morgan County sediment basin outlet and inlet water sample soil mass values and percent mass and concentration reduction in the basin.

				Inlet Values			Outlet Values				
Event #	**Start Date**	**Cum. Precip (in)**	**Duration (hrs)**	**Volume (L)**	**Conc. (g/L)**	**Soil Mass (kg)**	**Volume (L)**	**Conc. (g/L)**	**Soil Mass (kg)**	**Mass Reduction (%)**	**Conc. Reduction (%)**
6	6/24/2017	1.28	1.4	161.8×10^3	23.3	3765.4	44.1×10^3	6.0	264.2	93.0	74.3
8	7/1/2017	0.43	2.1	13.4×10^3	165.7	2219.1	44.1×10^3	8.4	372.4	83.2	94.9
9	7/3/2017	0.77	32.7	24.5×10^3	52.8	1295.3	44.1×10^3	11.1	489.2	62.2	79.0
10	7/5/2017	0.87	0.8	72.7×10^3	10.0	730.3	44.1×10^3	8.7	382.0	47.7	13.0
14	8/6/2017	0.53	6.5	7.9×10^3	31.0	245.9	4.6×10^3	1.3	6.2	97.5	95.8
15	8/7/2017	0.88	9.8	48.2×10^3	69.4	3347.1	44.1×10^3	17.5	769.4	77.0	74.8
									Average	**76.8**	**72.0**

outlet SCC values were not significantly different.

Morgan County precipitation during the monitored time period compared to mass reduction percentages was compared in Figure 4-4. This data reflects how time between events can affect basin performance. There were short durations without rainfall between sampling events, meaning consecutive events, in some cases less than 48 hours. Performance reduction percentages were reduced in sequence between events on July 1st, 3rd, and 5th as well as between events on August 7th and 8th.

At the Knox County site, the mass percent retained in the basin was an average of 97.4%, with a range between 94.3% and 99.4% retention. The data also had a median of 98.1% and a standard deviation of 1.98%. The data was normally distributed with a p-value of 0.5934. The average SCC reduction ranged between 75.6% and 97.4%, with an average reduction of 86.7%. Table 4-12 shows summary data for the percentage mass retained in the basin based on inlet and outlet values for Knox County, as well as SCC reduction, time, and precipitation information for the events.

An event matched pair analysis for Knox County was run on the mass and SCC values for inlet and outlet. A test for normality was completed, the mass inlet and outlet values were found to not fit the normal distribution with p-values of 0.0041 and 0.0006, however, the SCC values were normally distrusted. The mass data was logarithmically transformed, and the variables were normally distributed with p-values of 0.2826 and 0.4164. The lognormal transformed mass data and untransformed SCC values were analyzed using a paired t-test. When comparing sediment mass values from inlet to outlet at Knox County, the t-ratio was -10.35 with a degree of freedom of 4. The mean difference between the inlet and outlet masses was -3.88×10^{-3} kilograms. The p-value of 0.0005 indicates the null hypothesis was rejected and the inlet and outlet mass values were significantly different. Comparing SCC values, the t-ratio was approximately -3.39 with a degree of freedom of 4. The mean difference between the inlet and outlet concentrations was -0.00002 g/L. The p-value of 0.0275 indicates that there was a significant difference between the inlet and outlet SSC values.

Knox County construction site precipitation over time compared to percentage of mass retained in the basin as a performance variable was analyzed in Figure 4-5. At the Knox County site there was often over five days of no precipitation in between monitored events. There was also less variation in mass reduction values in Knox County.

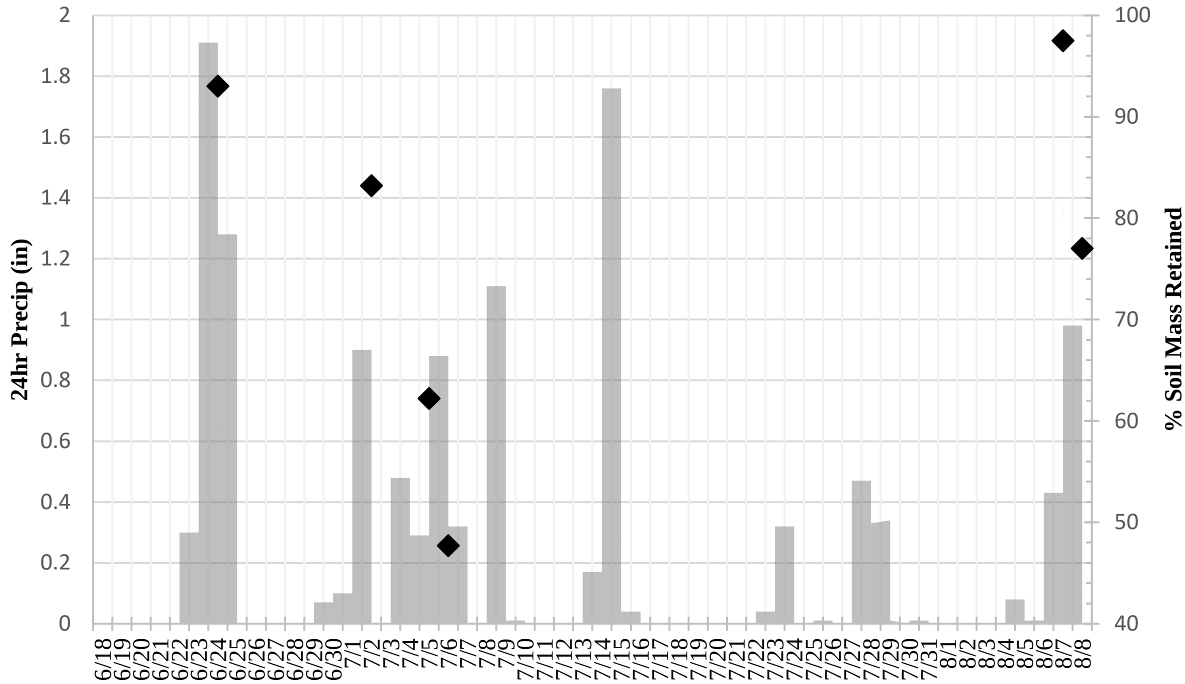

Figure 4-4. Graph of Morgan County 24-hour precipitation in inches compared to percent of soil mass retained, indicating how performance is affected by proximity of precipitation events.

Table 4-12. Knox County sediment basin outlet and inlet water sample soil mass values and percent mass and concentration reduction in the basin.

				Inlet Values			Outlet Values				
Event #	**Start Date**	**Cum. Precip (in)**	**Duration (hrs)**	**Volume (L)**	**Conc. (g/L)**	**Soil Mass (kg)**	**Volume (L)**	**Conc. (g/L)**	**Soil Mass (kg)**	**Mass Retained (%)**	**Conc. Reduction (%)**
1	7/23/2017	0.65	2.0	20.4×10^3	11.6×10^{-6}	0.236×10^{-3}	4.1×10^3	1.9×10^{-6}	0.008×10^{-3}	96.6	83.6
2	7/28/2017	0.77	8.3	25.2×10^3	45.8×10^{-6}	1.155×10^{-3}	5.2×10^3	4.3×10^{-6}	0.022×10^{-3}	98.1	90.6
3	8/6/2017	0.58	10.0	17.7×10^3	10.3×10^{-6}	0.182×10^{-3}	2.1×10^3	1.4×10^{-6}	0.003×10^{-3}	98.4	86.4
5	8/31/2017	0.49	19.3	17.1×10^3	19.2×10^{-6}	0.328×10^{-3}	3.8×10^3	0.5×10^{-6}	0.002×10^{-3}	99.4	97.4
6	9/5/2017	1.15	23.7	217.3×10^3	27.9×10^{-6}	6.051×10^{-3}	50.7×10^3	6.8×10^{-6}	0.344×10^{-3}	94.3	75.6
									Average	**97.4**	**86.7**

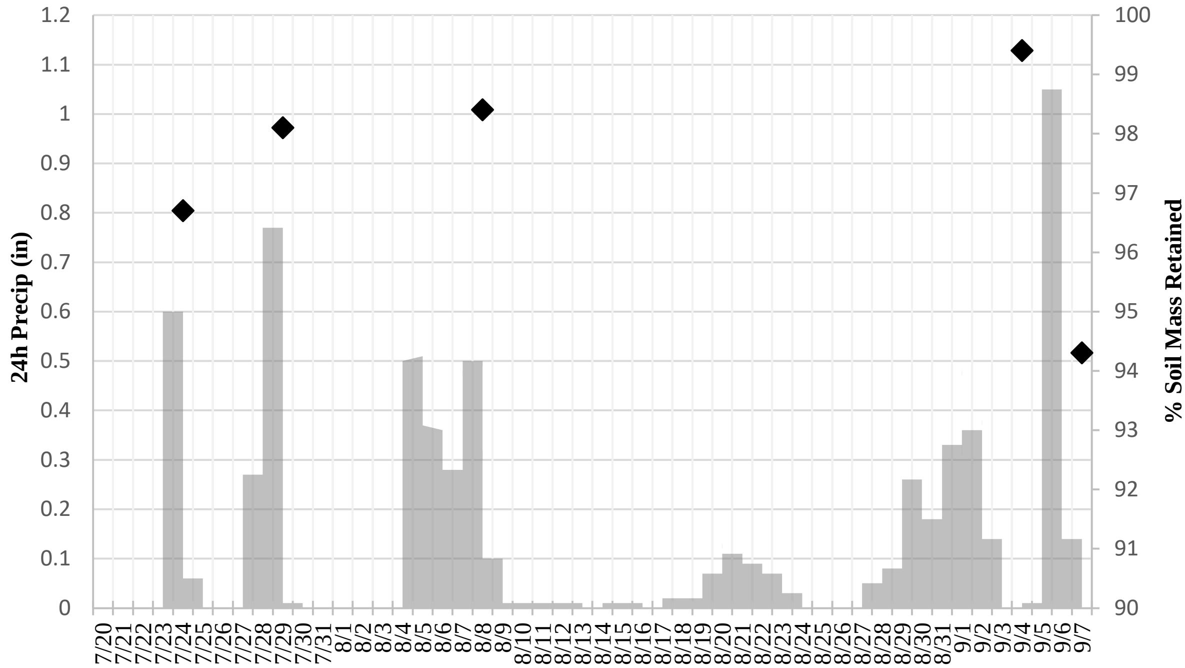

Figure 4-5. Graph of Knox County 24-hour precipitation in inches compared to percent of soil mass retained, indicating how performance is affected by proximity of precipitation events.

4.5 Catchment Sediment Yield Modeling

RUSLE2 was utilized to compare the measured soil yields to the modeled results. The model inputs for Morgan County were as follows. The soil was a silt loam, low to medium organic matter, medium permeability, and 5% rock. The management was highly disturbed\bare - bare, cut, smooth. The steepness was 10% and the length was estimated as 255 feet. The operational input was no operation. The adjusted residual burial level was normal. The rainfall erosivity was taken from the six Morgan County measured rainfall events (Table 4-5). The soil loss from the catchment slopes estimated by the Morgan County RUSLE2 run was 19 t/ac, and the measured field value was 22 t/ac.

For Knox County, the soil input was sandy loam and 10% rock. The management was highly disturbed\bare - bare, cut, smooth. The steepness was 4% and the length was an estimated 230 feet. The operational input was no operation. The adjusted residual burial level was normal. The rainfall erosivity was taken from the five Knox County measured rainfall events (Table 4-6). The soil loss from the catchment slope estimated by the Knox County RUSLE2 run was 3.8 t/ac, and the measured value was 0.13 t/ac.

5.0 DISCUSSION

The variability of soil particle size in a catchment area influences the erodibility of the soil (ARS 2016). This influences the amount of sediment that enters the sediment basin, but it also affects the performance of the basin because larger particles will have a better likelihood of dropping out (TNWRRC n.d.). The laboratory data paired with the USDA classification of soil concluded that the Knox County soil is a sandy loam ranging from extremely to very gravely. The Web Soil Survey was inconclusive about the soil at this location because the location is highly urbanized and disturbed. Additional soils from the catchment area included the Apison-Montevallo complex, a gravelly silt loam/gravely loam, and the Bloomingdale-Hamblem complex, a silt loam/clay loam (Soil Survey Staff n.d.). The laboratory results varied significantly compared to the Web Soil Survey classification (Table 4-2). Attempting to classify a soil at a construction site based on Web Soil Survey is not an appropriate method. Construction site soil has often been so disturbed that the natural layers are unrecognizable. In order to size a BMP using RUSLE2 it is important to have a clear understanding of rock cover and soil type. The findings in this field research suggest for the sake of soil classification accuracy a catchment field soil sample be taken and classified when BMP design is occurring in order to best understand the truer nature of soil loss from the site.

An aspect of monitoring stormwater pollutants is characterizing flow measurements. This was accomplished by utilizing an H-flume equipped with a pressure transducer at both Morgan County and Knox County. As sediment laden water flowed from the catchment slope and into the approach area, the inlet flume structure and wingwalls slowed down the water and assisted in settling out the suspended sediment. The structure unintentionally behaved as a check dam or a forebay. This is clear by the mass of deposition that occurred with each storm at both sites (Table 4-3 and Table 4-4). The mass of the soil deposited in the approach area was not utilized in the calculation of performance in the flume for percent mass removal because the soil deposited did not make it into the basin. Not including this soil likely underestimated the mass removal of sediment for the entire system at both basins. It was the intention to monitor a basin built to current TDOT standard design, this does not include a forebay. Regardless, the flume was mirroring the design aspect of a forebay, a tool that is required by TDEC standards and needs to be included in the sediment basin design, these results emphasize the usefulness of this design aspect at the inlet of the basin (TDEC 2012).

The results for approach channel deposition at both Morgan County and Knox County did not show a trend in greater or lesser amounts of soil being deposited over time (Table 4-3 and Table 4-4). There was a trend in amount of soil deposited depending on the 30-minute intensity of the storm. Figure 4-1 indicated an upward sloping linear trend in 30-minute intensity to sediment deposit depth in the approach area. This observation helps characterize the relationship between precipitation and the catchment soil surface and therefore have a better understanding of what the inputs will be into the sediment basin.

The total mass of various deposited samples does not explain the entire story of the sediment basin. To understand, it is critical to look at particle size mass variation between samples. Morgan County saw reduction in all particle sizes between the inlet plus approach values and the outlet values. The lowest reduction being between the silt masses, with a reduction of 72.4%. This was likely due to the alteration of length to width ratio, potentially causing short circuiting. This basin was sized/modeled to the surface water recommendation of having more mass removal of silt than occurred in the field (Table 4-7). This result emphasizes the scaling issue of sediment basins based on current standards, especially for small contributing areas. Knox County had consistently high removal of 100% to 99% for all sediment classification sizes, yet the inputs mass values were low compared to Morgan County (Table 4-8). Variation from true sediment values likely occurred at both sites due to the monitoring systems (i.e. automated sampler preferential size sampling, flume affects, etc.), but the emphasis was seen much more at Knox County due to its small contributing mass values from the catchment basin (Table 4-12).

Sediment basin performance varied between the two monitored sites. Morgan County had an average sediment reduction of 76.8% and Knox County had an average sediment reduction of 97.4% (Table 4-11 and Table 4-12). One way that this could have been remediated was by using baffles or flocculants at the Morgan County site. The soil was classified as a silt loam, which makes the basic basin design typically only 75% effective (TNWRRC n.d.). The Knox County site performed higher in settling mass removal percentages but had much lower delivered mass from the catchment and a higher large particle size classified soil. These basins are expected to perform better than one with a catchment composed of predominantly small particle size classified soils. The average mass removal at Morgan County was 76.8% removal. The Morgan County site consistently had much greater amounts of contributing sediment to the basin from the catchment area. Moreover, there were many consecutive events at the Morgan County site, which could contribute to the lower removal yields (Figure 4-4). This occurred between storm nine and ten, which only had two days between them and the previous event; storm eight, only had two days between it and storm nine. The results of the statistical analysis yielded that the there was significant correlation between inlet and outlet mass values.

Knox County basin performance was very high, yet the total mass going into the basin was very low. Assessing these results, an alternative BMP would have been a less expensive and equally effective tool for the Knox County site. The lognormal mass values for inlet and outlet sediment yields at Knox County shows significance in the difference between the two values. The mass values and removal percentages at the Knox County site were often analyzed after a large amount of time had passed between events, no event occurred any closer than 5 days of another (Figure 4-5).

Comparing this sediment basin research to the research done by other researchers detailed in Section 2.2.2 helps shed light on the nuances of sediment basin design. Sediment mass retention in the floating skimmer basin Millen et al. (1997) was similar to that of Knox County, with an average retention of 96.8% compared to Knoxville at 97.4%. There was a slight difference in the sediment used, a silt loam that lacks larger gravel and sediment. Some differences can be contributed to the fact that tests run by Millen et al. (1997) were in a highly controlled experimental environment, one that delivered sediment to the basin by injecting it into the system.

The construction site sediment basin experiment by McCaleb and McLaughlin (2008) exhibited similar but slightly higher removal rates compared to the Knox County basin. Their basin included baffles but had a similar dewatering device to the two TDOT monitored basins. The trapping efficiency was over 99% for their device (McCaleb and McLaughlin 2008). Morgan County had an average mass retention of 97.4% and 76.8% for Knox County.

The basin experiment by Fang et al. (2015) had some similar and some different elements to the TDOT basins. The Fang et al. basin used a skimmer but included baffles and PAM blocks. The basin was also being tested on a construction site. It was unclear what the receiving soil type from the catchment was. The monitoring was also being done with portable automatic samplers and an inflow weir. The efficiency of removal for the site for event one in November, when PAM was being used correctly, was 96.6% by concentration and 97.9% by total mass. The efficiency of removal for event two in December, when PAM was being used incorrectly, was 76.0% by concentration and 83.7% by total mass (Fang et al. 2015). The first storm reflects more similar removal to the Knox County site, where the second storm reflects more similar removal rates to Morgan County. As a result of the study by Fang et al. it was suggested that a minimum volume to catchment area ratio of 251.9 m^3/ha (3,600 ft^3/ac) be used. The Morgan County basin was designed to have a total volume of 2,494.8 ft^3 for a drainage catchment of 0.6 acres. These values produce a ratio of 4,158 ft^3/ac, a 15.5% increase in the size of the suggested basin. The Knox County basin was designed to have a total volume of 5,030 ft^3 for a drainage catchment of 1.75 acres. These values produce a ratio of 2,874 ft^3/ac. The Knox County basin, which performed better, resulted in a lower ratio, thereby not holding up to the suggested standard by Fang at al. (2015). This shows that sizing cannot be done linearly, rather the orientation and length to width ratio have more influence on the basin. It is important to understand the limitations of attempting to fit a linear scale on a turbulent system.

Hydrologic catchment sediment modeling, RUSLE2, yielded similar result for sediment yield at the Morgan County site with a value of 19.0 t/ac compared to 22.0 t/ac estimated from the field. This is an underestimation of 3.0 t/ac. The modeling efforts for Knox County fielded similar results with an estimated 3.8 tons, where the measured field results were 0.13 t/ac. This is an overestimation of 3.67 t/ac. RUSLE2 does not include estimates for channelization of flow, modeling values as similar as this to field results is satisfactory for not including a major source of characterization in erosion from construction sites, especially in longer corridors. This research emphasized the utility of this tool for sizing sediment storage volumes in sediment basins.

As in most projects, there were some valuable qualitative observations taken from the time spent monitoring the two sediment basins. The first issues were that the Morgan County sediment basin site was originally planned and constructed for a larger drainage basin size (2 acres) but was constructed in a site that would continuously flow with groundwater discharge/upland slope water (Figure E-1, Figure E-2, and Figure E-3). This presented a major issue because the basis for sediment basin design is that the basin be dry in between events. It also made sampling an issue because the sediment detention time was infinite, meaning there was no outlet trigger time or outlet volume zero beginning time. The lesson learned from this is to be careful about placing a basin in a location with seasonally high-water tables or in wetland areas.

The next issue deals with site location due to placement in a highway construction site. The Morgan County site was eventually built up slope, out of the water table. This basin was smaller and was manipulated in order to fit in the space between the slope and the beginning of water outfall from highway drainage (Table 3-2). This resulted in a reversed length to width ratio, which likely contributed to the prevalence of sand sized particles in the outlet due to short circuiting of the basin (Table 4-9). It is important to recognize changes from the drawings to the construction site. Sediment basins are relatively simple; however, small details like this one cause big effects in particle size removal. The design should have been revisited and the addition of a baffle should have been made to allowed for better sediment capture (TNWRRC, n.d.). This being noted, overall it is important to understand the constraints of a linear corridor and be able to alter a typical design if the constraints impact the potential performance of the basin, making it even more critical to install the basin correctly.

The next issue was of minimal effect for the two basins monitored but could potentially be an issue elsewhere. It is important to route clean water around the basin. There was potential for this to be an issue at the original Morgan County basin because it had a large amount of contributing forest runoff; therefore, extra precautions were taken to route the water around the monitored Morgan County basin.

A final observation, the rapidity of work on transportation projects and the number of storms that occur during construction influence the monitoring effort. In research, it is important to have an appropriate number of replicates in order to see trends. The variability in soil erosion alone emphasizes the need for replicates. The original proposal entailed that each monitored site would take data from ten storms. Each site had roughly 6 weeks of monitoring time and produced six and five usable storm event collection periods. The time constraints of fast moving construction made monitoring the sites difficult. This should be taken into consideration when trying to monitor field construction sites.

It is important in future research to understand that site erosional behavior, especially in construction, is incredibly variable. This emphasizes the need to base any design assumptions on true field site characteristics, utilizing the best current design tools to make engineering decisions. It is also important to understand when a design is the best option and when it is not, not basing this off convince, but rather scientific evidence and research.

6.0 CONCLUSION

This project assessed two TDOT sediment basins and their performance. Valuable information was gained through the assessment of the Morgan County and Knox County site sediment basins. The Morgan County basin performed at an average of 76.8% mass sediment reduction between the influent and effluent. The Knox County basin performed at an average of 97.4% mass sediment reduction between the influent and effluent. The variability in storm frequency, duration, and intensity contributed to the effectiveness of the basins. The catchment soil between the two sites varied greatly; Knox County had a higher prevalence of larger particles, specifically gravel, when compared to Morgan County. Additionally, there was a large difference in contributing mass volumes between the two sites; Morgan County had an average inlet mass of 1.93×10^{3} kilograms of soil compared to Knox County, which had an average inlet mass of 1.6×10^{-3} kilograms of soil.

Moving forward, the third basin in Bedford County should be treated as the previous two basins were. An assessment should be run for basin performance and catchment characterization. This assessment will contribute to the understanding of which factors (soil, design, etc.) were most important to influencing performance. It would be beneficial for the monitoring to occur more than five or six times at the third site. This field monitoring will continue the phase two research started in this thesis of the overall project started by Neff and Schwartz (2013).

Various recommendations from this study can be made in order to help TDOT revise their design drawings. To begin, field verification of soil types for use in RUSLE2, will assist in gaining a more accurate assessment of catchment slope behavior. This is critical because of the variability between true soil classification and Web Soil Survey from construction soil manipulation. Second, utilize best available technology, RUSLE2, as a tool in estimating soil volume storage in the sediment basin, yet recognizing RUSLE2 only estimates rill and interill erosion. RUSLE2 can be used to estimate sediment storage and storm size standards for 72-hour detention can be used to size the hydraulic storage volume. Next, consider the importance of the length to width ratio when both designing the basins and implementing them in the field, making the necessary changes if the ratio is altered (i.e. baffles). Further, consider the addition of a forebay for large sediment settling, especially in smaller basins where this research saw the contribution of sand to the outlet, an occurrence that should not have happened. In addition, understand that basin design is not linear, and that erosion and sediment transport is complicated and deals with turbulence, a non-scalable condition. Finally, emphasizing the importance of variability in design and usefulness of sediment basin, highway sites are linear corridors with difficult to quantify contributing areas. Although useful, sediment basins are not going to be the most cost efficient and appropriate BMP at every highway construction site, but when they are, ensure that they are designed appropriately and implemented with care, taking into account alternative additions if needed (i.e. flocculants).

REFERENCES

Agricultural Research Service (ARS). (2016). “Revised Universal Soil Loss Equation 2”. Watershed Physical Processes Research: Oxford, MS. <https://www.ars.usda.gov/southeast-area/oxford-ms/national-sedimentation-laboratory/watershed-physical-processes-research/research/rusle2/> (Jul. 20, 2018).

ASTM (2017). “Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis.” Standard D6913/D6913M, ASTM International, West Conshohocken, PA.

Ehrhart, B.J., Shannon, R.D., and Jarrett, A.R. (2002). “Effects of Construction Site Sedimentation Basins on Receiving Stream Ecosystems.” Transactions of the ASAE, American Society of Agricultural Engineers, 45(3), 675-680.

Fang, X., Zech, W.C., and Logan, C.P. (2015). “Stormwater Field Evaluation and Its Challenges of a Sediment Basin with Skimmer and Baffles at a Highway Construction Site.” *Water*, 7, 3407-3430.

Fennessey, L.A.J. and A.R. Jarrett. (1994). “The dirt in a hole: A review of sedimentation basins for urban areas and construction sites.” *Journal of Soil and Water Conservation*, 49(4), 317-323.

Fennessey, L.A.J. and A.R. Jarrett. (1997). “Influence of Principal Spillway Geometry and Permanent Pool Depth on Sediment Retention of Sediment Basins.” *Soil and Water Division,* ASABE, 40(1), 53-59.

Gabriels, D., Ghekiere, G., Schiettecatte, W., and Rottiers, I. (2003). “Assessment of USLE cover-management C-factors for 40 crop rotation systems on arable farms in the Kemmelbeek watershed, Belgium.” *Soil and Tillage Research*, 74(1), 47-53.

Glenn, J.S. and Bartell, E.M. (2008). “Mixing Things Up: Preventing Short-Circuiting in Stormwater Ponds.” *World Environmental and Water Resources Congress 2008 Ahupua’a*, Honolulu, HI, 316, 1-10.

Hangul, A.R. (2017). “In Service Performance Evaluation of Erosion Prevention Sediment Control Devices.” Master’s Thesis, University of Tennessee, Knoxville.

Henley, W.F., Patterson, M.A., Neves, R.J., and Dennis Lemly, A. (2000). “Effects of Sedimentation and Turbidity on Lotic Food Webs: A Concise Review for Natural Resource Managers.” *Reviews in Fisheries Science*, 8(2), 125-139.

Hillel, D. (1998). *Environmental Soil Physics*, Academic Press, San Diego, CA, 15, 443-444.

Iyer, S. (2007). “Highway Storm Water Runoff: BMP Design Considerations.” *Storm Water Solutions.* <https://www.estormwater.com/highway-storm-water-runoff-bmp-design-considerations> (Aug. 15, 2018).

Low Impact Development Center (LIDC). (2006) “Evaluation of Best Management Practices for Highway Runoff Control.” *LID Design Manual.* <https://www.coralreef.gov/transportation/evalbmp.pdf> (Aug. 15, 2018).

McCaleb, M.M. and McLaughlin, R.A. (2008) “Sediment Trapping by Five Different Sediment Detention Devices on Construction Sites.” *Soil and Water Division,* ASABE, 51(5), 1613-1621).

Mid-America Regional Council (MARC). (n.d.). “Winter Watershed Tip.” <https://cfpub.epa.gov/npstbx/files/ksmo_sediment.pdf> (Jul. 1, 2018).

Millen, J.A., Jarrett, A.R., and Faircloth, J.W. (1997). “Experimental Evaluation of Sediment Basin Performance for Alternative Dewatering Systems.” Transactions of the ASAE, American Society of Agricultural Engineers, 40(4), 1087-1095.

Neff, K.J. and Schwartz, J.S. (2013). "Engineering Design Guidance for Highway Construction Sediment Basins." TDOT Final Report. Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, Tennessee.

National Soil Erosion Research Laboratory (NSERL). (n.d.). "Interrill Erosion*." Soil Erosion and WEPP Technology*, USDA-ARS, Perdue University. <http://milford.nserl.purdue.edu/weppdocs/overview/intrrll.html> (Aug. 15, 2018).

Natural Resources Conservation Service (NRCS). (2000). "Erosion and Sedimentation on Construction Sites." *Soil Quality – Urban Technical Note No. 1*, Soil Quality Institute, Auburn, Alabama.

North Carolina Department of Transportation (NCDOT). (2015). "Erosion and Sediment Control Design and Construction Manual." <https://connect.ncdot.gov/resources/hydro/HSPDocuments/NCDOT_ESC_Manual_2015.pdf> (Aug. 15. 2018).

NRCS. (2015). "Ephemeral and Classic Gully Erosion Worksheet." *USDA-NRCS*, Section I – General Resource References, Wisconsin. <https://efotg.sc.egov.usda.gov/references/public/WI/Gully_Erosion_Prediction.pdf> (Aug. 2, 2018).

Perez, M., Fang, X., Zech, W.C., and Vasconcelos, J. (2015). "Design and Construction of a Large-scale Sediment Basin and Preliminary Testing Results." ALDOT Research Report, Highway Research Center, Herbert Engineering Center, Auburn, AL.

Pinson, W.T., Yoder, D.C., Buchanan, J.R., Wright, W.C., and Wilkerson, J.W. (2004). "Design and Evaluation of an Improved Flow Divider for Sampling Runoff Plots." *Applied Engineering in Agriculture*, ASABE, 20(4), 433-438.

Pitt, R. (2003). “The Design, Use, and Evaluation of Wet Detention Ponds for Stormwater Quality Management.” Department of Civil and Environmental Engineering, University of Alabama, Tuscaloosa, AL.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C. (1997). “Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE).” United States Department of Agriculture (USDA), Agricultural Research Service, Agricultural Handbook Number 703.

Schaner, G. and Farris, E. (2012). “U.S. EPA Webinar on the 2012 Construction General Permit.” *EPA.* <https://www3.epa.gov/npdes/outreach_files/sw_cgp_webinar_march2112.pdf> (Aug. 1, 2018).

Soil Survey Staff. (n.d.). Web Soil Survey. Natural Resources Conservation Staff, United States Department of Agriculture. <https://websoilsurvey.sc.egov.usda.gov/?referrer=Citation.htm-HomeLink1> (Apr. 4, 2017).

Stanley, D.W. (1996). “Pollutant Removal by a Stormwater Dry Detention Pond.” *Water Environment Research*, 68(6), 1076-1083.

Sturm, T.W. (2010). *Open Channel Hydraulics,* 2nd Ed., New York, New York.

Tennessee Department of Environment and Conservation (TDEC). (2012). *Erosion & Sediment Control Handbook,* 4th Ed., Nashville, Tennessee.

Tennessee Department of Transportation (TDOT). (2012). “Chapter 10: Erosion Prevention and Sediment Control.” *Drainage Manual,* Nashville, Tennessee.

TDOT. (2017). “Standard Roadway Drawings: Erosion Prevention and Sediment Control”. <https://www.tn.gov/tdot/roadway-design/standard-drawings-library/standard-roadway-drawings/erosion-prevention-and-sediment-control.html> (Jul. 14, 2018).

TDOT. (2018). “About TDOT.” <https://www.tn.gov/tdot/about.html> (Mar. 4, 2018).

Tennessee Water Resources Research Center (TNWRRC). (n.d.). “Frequently Asked Questions for Sediment Basin”. <http://tnepsc.org/Current%20FAQ%20for%20Sed%20Apr%202013.pdf> (Jul. 15, 2018).

United States Environmental Protection Agency (US EPA). (1999). “Preliminary Data Summary of Urban Storm Water Best Management Practices.” Office of Water, Washington, DC, EPA-821-R-99-012.

US EPA. (2011). “Summary of State Stormwater Standards.” Office of Water, Office of Wastewater Management, Water Permits Division. <https://www3.epa.gov/npdes/pubs/sw_state_summary_standards.pdf> (Aug. 2, 2018).

US EPA. (2017). “History of the Clean Water Act.” < https://www.epa.gov/laws-regulations/history-clean-water-act> (Jul. 1, 2018).

US EPA. (n.d.) “Appendix H – Compliance with the C-Factor Stabilization Criteria.” *Proposed Construction General Permit.* <https://www3.epa.gov/npdes/pubs/cgp_appendixh.pdf> (Aug. 2, 2018).

Walters, G.S. (2011). “EPA’s New Stormwater Effluent Limitation Rules.” *Smith Currie.* <https://www.smithcurrie.com/publications/common-sense-contract-law/epas-new-stormwater-effluent-limitation-rules/pdf/> (Jul. 20, 2018).

Water Environment & Reuse Foundation (WERF). (2017). "Final Report." *International Stormwater BMP Database: 2016 Summary Statistics,* Alexandria, Virginia.

WERF. (2018). *International Stormwater BMP Database,* Alexandria, Virginia.

Willett, G. (1980). "Urban Erosion." *National Conference on Urban Erosion and Sediment Control; Institutions and Technology*, EPA, 905/9-80-002.

Wood, P.J. and Armitage, P.D. (1997). "Biological Effects of Fine Sediment in the Lotic Environment." *Environmental Management*, 21(2), 203-217.

Zech, W.C., Fang, X., and Logan C. (2012). "State-of-the-practice: Evaluation of Sediment Basin Design, Construction, Maintenance, and Inspection Procedures." ALDOT Research Report No. 1, Highway Research Center, Harbert Engineering Center, Auburn, AL, Project Number: 930-791.

APPENDICES

APPENDIX A: Figures and Tables for Sizing Basins

Table A-1. Final basin size determinations, 100% silt and 25% clay removal (Neff and Schwartz 2013).

Region	Area (ac)	2.5*72 hour outflow - SCS Method (cfs)	Basin Length (ft)	Surface Area @4ft (ft^2)	Basin Volume (ac-ft)	% TDEC Basin
Knoxville	5	0.297	101	4826.25	0.339	82%
	10	0.594	136	7600.00	0.561	68%
	20	1.188	185	12512.25	0.967	58%
	30	1.782	223	17148.25	1.358	55%
	40	2.376	255	21612.25	1.739	52%
	50	2.970	283	25938.25	2.110	51%
Nashville	5	0.347	108	5332.00	0.379	91%
	10	0.695	145	8412.25	0.628	76%
	20	1.389	199	14136.25	1.104	66%
	30	2.084	239	19316.25	1.543	62%
	40	2.778	274	24505.00	1.987	60%
	50	3.473	304	29440.00	2.412	58%
Memphis	5	0.436	119	6176.25	0.446	107%
	10	0.872	161	9956.25	0.755	91%
	20	1.745	221	16886.25	1.336	80%
	30	2.617	266	23265.00	1.880	75%
	40	3.490	305	29612.25	2.427	73%
	50	4.362	339	35766.25	2.961	71%

Table A-2. Final floating outlet device sizing recommendations, based off Faircloth's guidance (Neff and Schwartz 2013).

Locale	Area (ac)	Final (100% Silt) Basin Volume (ac-ft)	Qout (ft3/d)	Diameter (in)	# Skimmers	Skimmer Size	Head(ft)
Knoxville	5	0.339	4918	2.28	1	2.5	0.167
	10	0.561	8149	2.66	1	3	0.250
	20	0.967	14046	3.25	1	4	0.333
	30	1.358	19720	3.85	1	4	0.333
	40	1.739	25246	4.35	1	5	0.333
	50	2.110	30640	4.79	1	5	0.333
Nashville	5	0.379	5499	2.41	1	2.5	0.167
	10	0.628	9112	2.81	1	3	0.250
	20	1.104	16024	3.47	1	4	0.333
	30	1.543	22398	4.10	1	5	0.333
	40	1.987	28849	4.65	1	5	0.333
	50	2.412	35029	4.85	1	6	0.417
Memphis	5	0.446	6478	2.37	1	3.0	0.250
	10	0.755	10958	2.87	1	4	0.333
	20	1.336	19398	3.81	1	4	0.333
	30	1.880	27303	4.53	1	5	0.333
	40	2.427	35246	4.86	1	6	0.417
	50	2.961	42998	5.37	1	6	0.417

APPENDIX B: TDOT Design Drawings

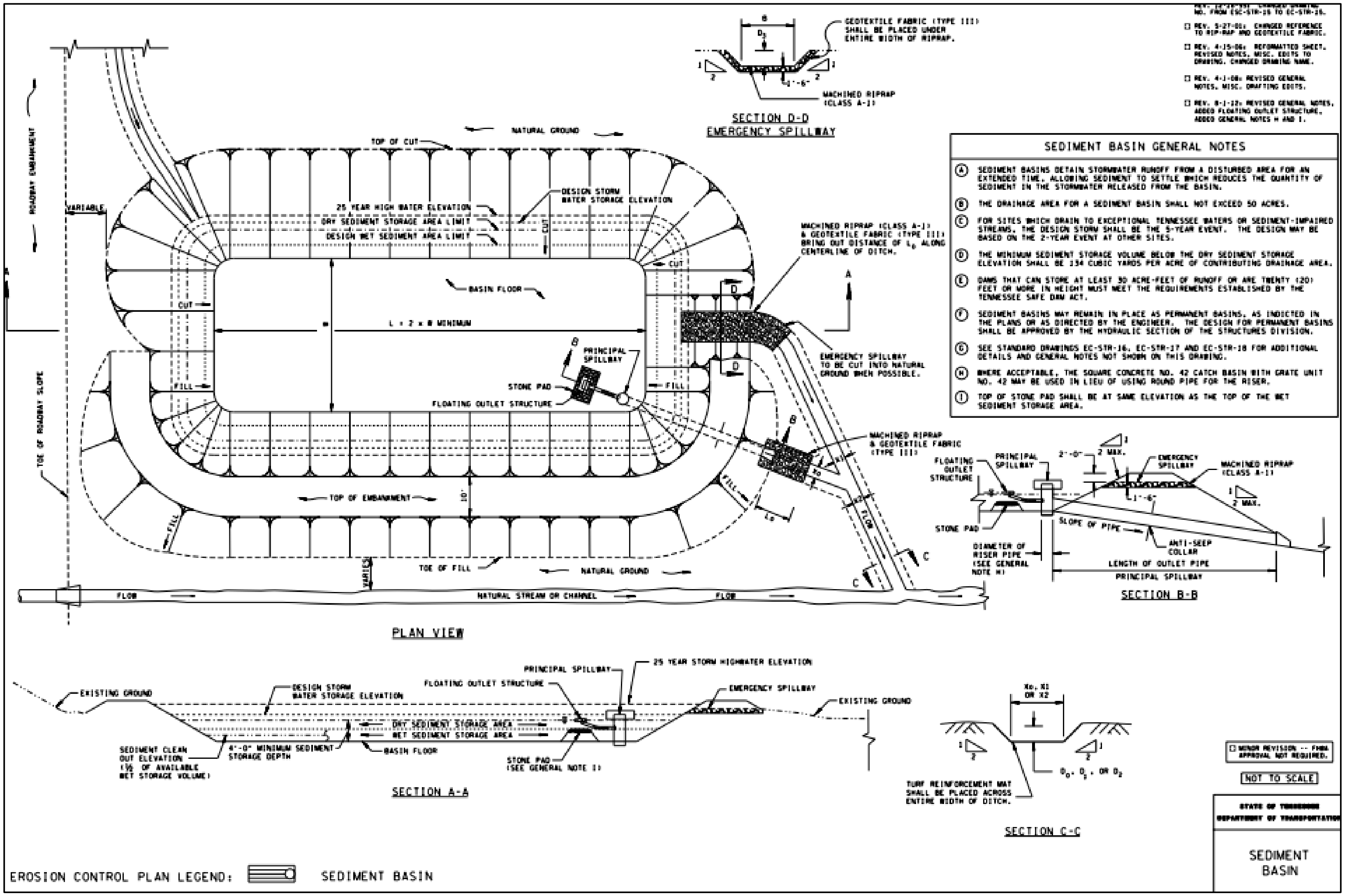

Figure B-1. Standard TDOT design drawing for a sediment basin (TDOT 2017).

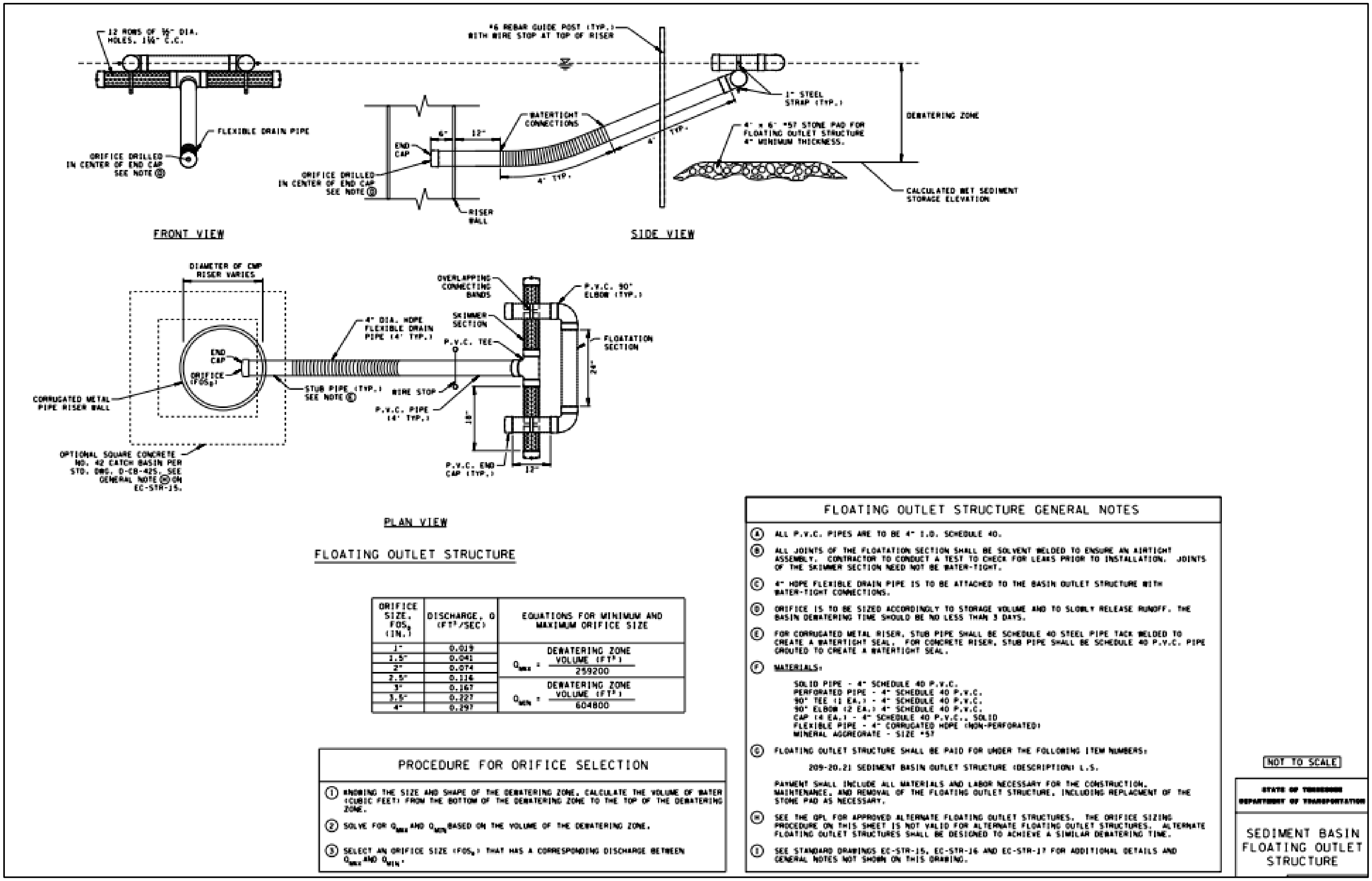

Figure B-2. Standard TDOT design drawing for sediment basin floating outlet structure (TDOT 2017).

APPENDIX C: Morgan County Design Drawings

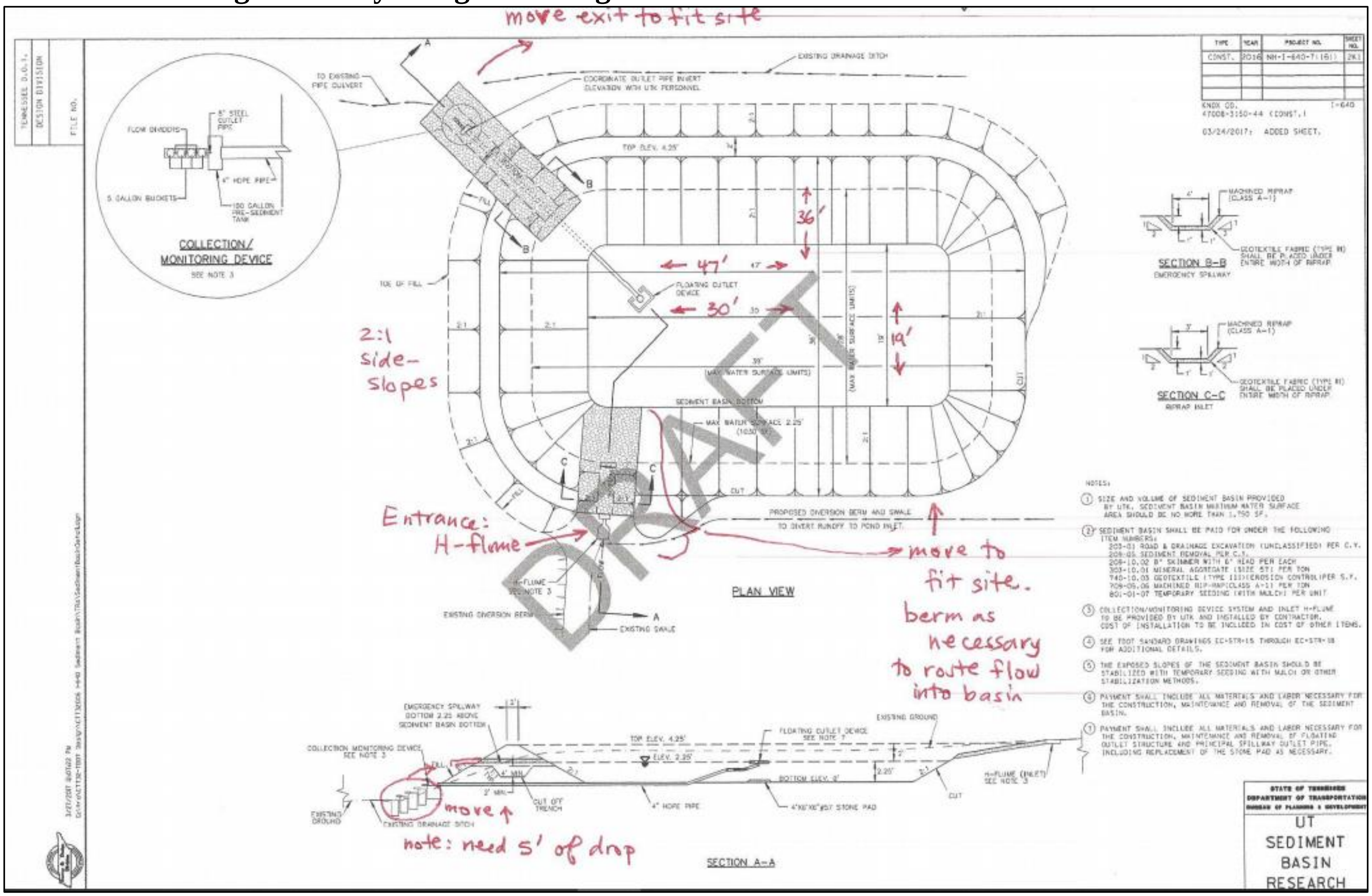

Figure C-1. Final Morgan County sediment basin design draft (revised from original basin built in Morgan County).

APPENDIX D: Knox County Design Drawings

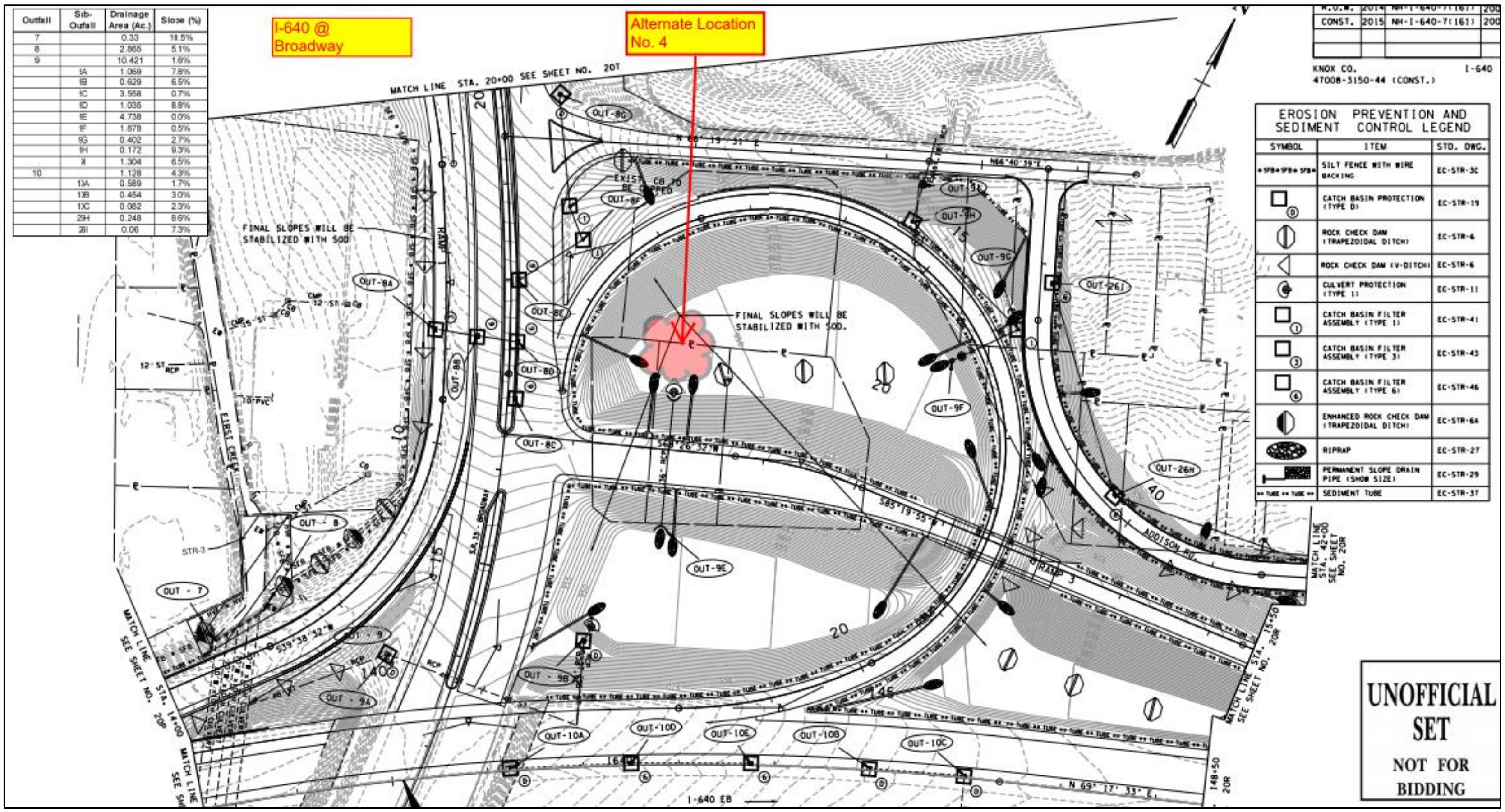

Figure D-1. Final location for Knox County sediment basin on future build plans.

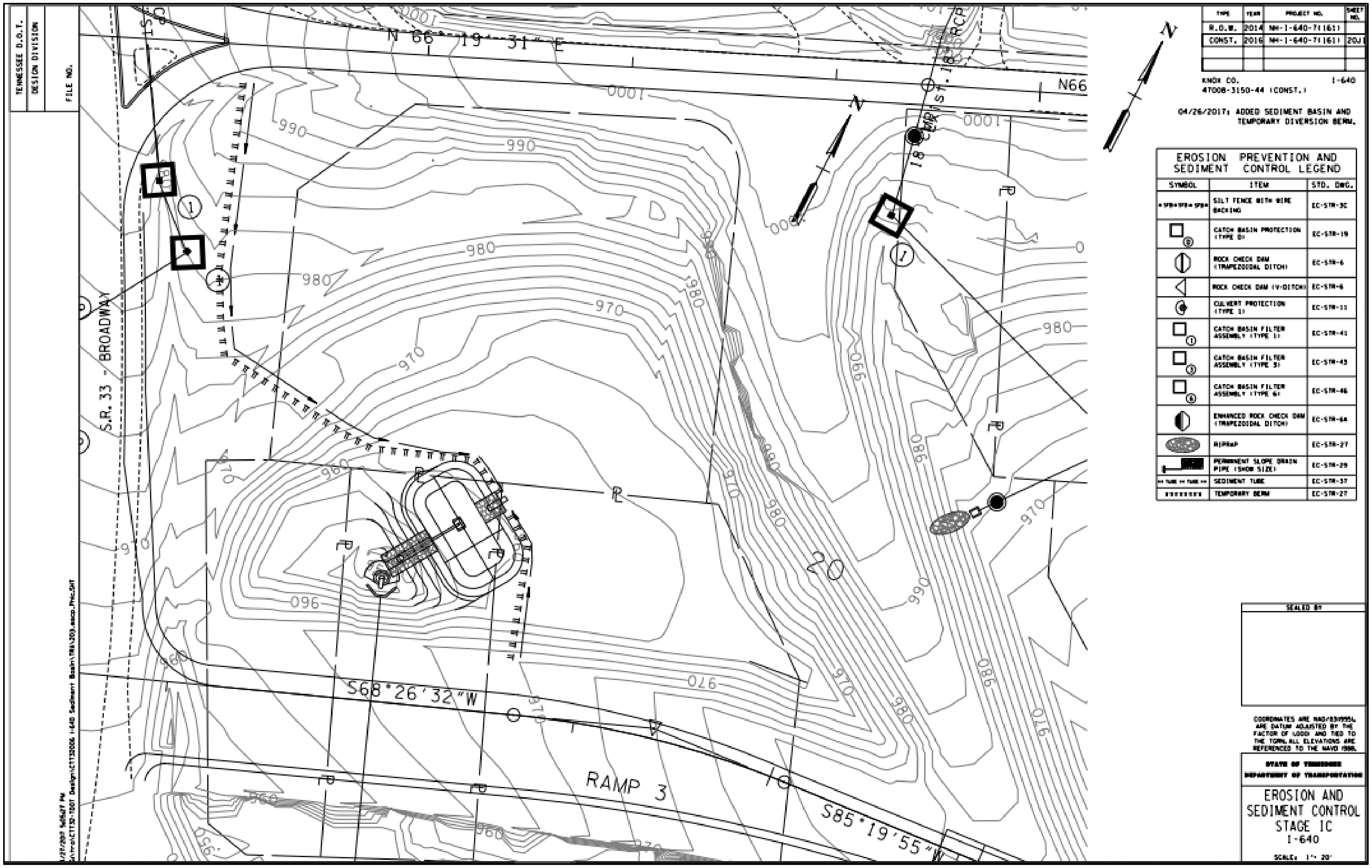

Figure D-2. Final location for Knox County sediment basin on contours, including drainage area delineation.

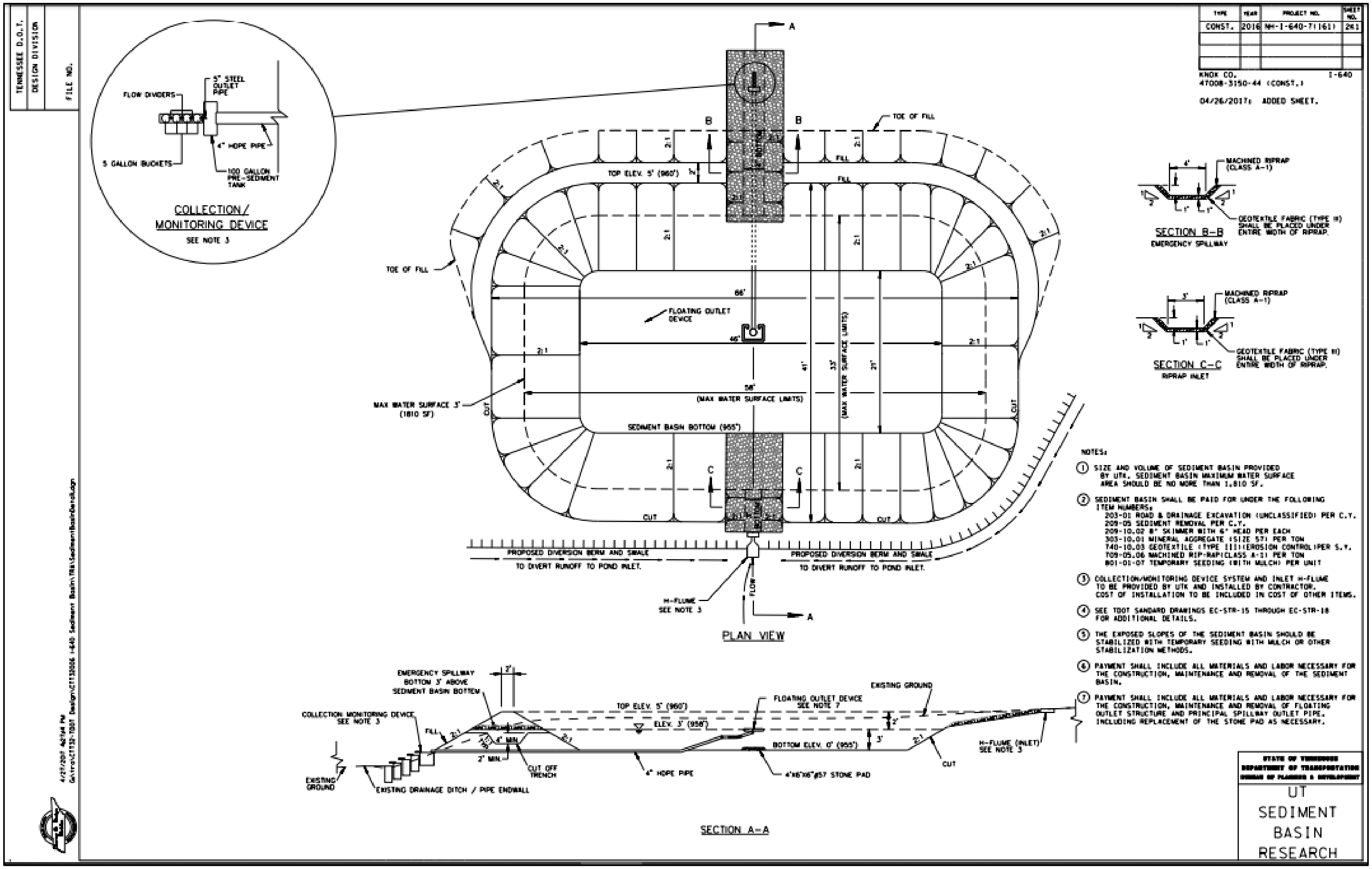

Figure D-3. Final design for Knox County sediment basin, without alteration to outlet monitoring at site.

APPENDIX E: Original Location Morgan County Design Drawings

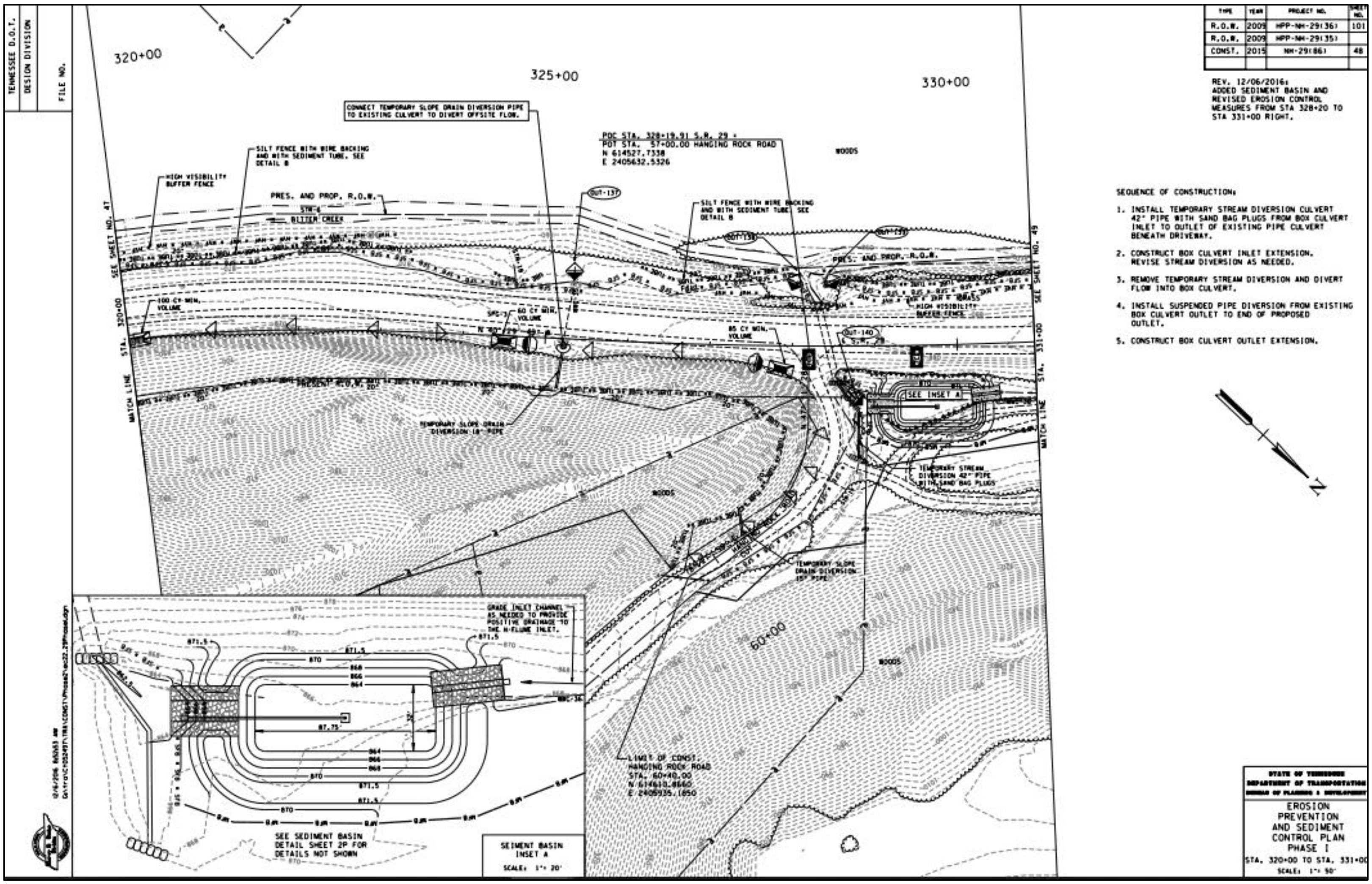

Figure E-1. Page one of the original placement and sizing of Morgan County sediment basin.

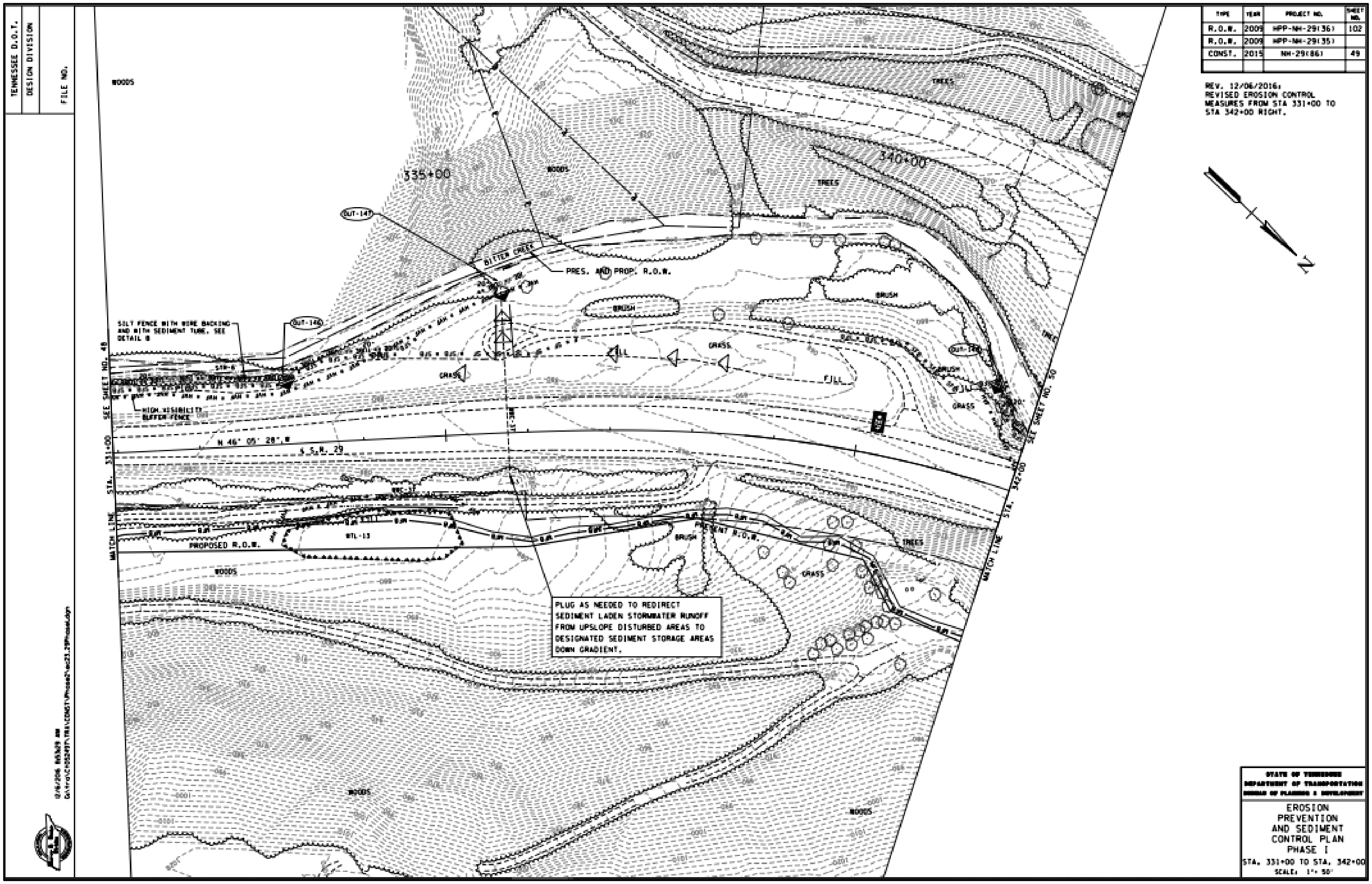

Figure E-2. Page two of the original placement and sizing of Morgan County sediment basin.

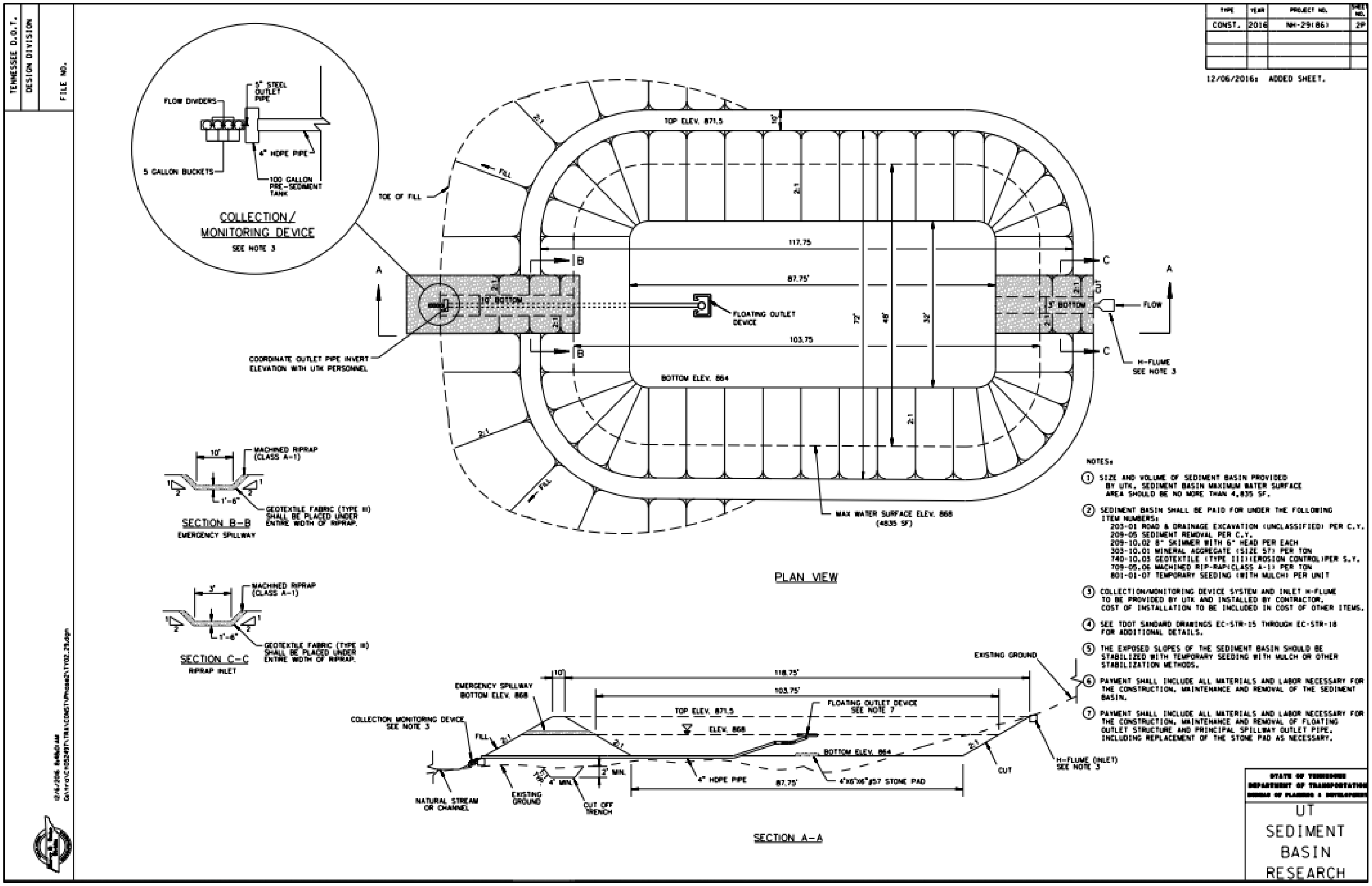

Figure E-3. Original design of Morgan County sediment basin, pre location change and size alteration.

VITA

Payton MacKenzie Smith is from Chattanooga, Tennessee where she graduated high school from the Chattanooga School for the Arts and Sciences (CSAS). She graduated from the University of Tennessee, Knoxville in spring of 2016 where she earned a Bachelor of Science in Biosystems Engineering. Payton was awarded a Graduate Research Assistantship from the Civil and Environmental Engineering Department at UT in the summer of 2016 in conjunction with the Tennessee Department of Transportation (TDOT). She is vice-president of the student water and environmental group Hydrolunteers.